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THE EFFECTS OF INCREASED MISSILE GUIDANCE SET INPUT RATE ON THE MINUTEMAN III MISSILE GUIDANCE SET REPAIR PROCESS AT THE AEROSPACE GUIDANCE AND METROLOGY CENTER

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The Aerospace Guidance and Metrology Center (AGMC) is a vital link in the Air Force's logistics support network. An important portion of AGMC's work load is the repair of the Minuteman III Missile Guidance Set (MGS). The importance of maintaining strategic missile operational capability dictates that AGMC be able to cope with current MGS work loads and to absorb changing work loads. If the average input rate were to increase due to changing mission requirements, AGMC managers would have to estimate what extra resources should be committed to MGS repair. The study is conducted using a GPSS V model to simulate the system level repair process for the MGS and the subsystem level repair process for the gyro stabilized platform. Through simulation of increased MGS input rate, the model identifies specific repair resource requirements at each of seven increased rates, up to 200 percent of normal. The simulation program with its extensive use of standardization and modularization, Macro statements that simplify coding and input of data, and indirect referencing, is a simplified approach to computer simulation.

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THE EFFECTS OF INCREASED MISSILE GUIDANCE SET INPUT RATE ON THE MINUTEMAN III MISSILE GUIDANCE SET REPAIR PROCESS AT THE AEROSPACE GUIDANCE AND METROLOGY CENTER

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

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In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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CHAPTER I

INTRODUCTION

Statement of the Problem

The Aerospace Guidance and Metrology Center (AGMC) at Newark AFS, Ohio, is a vital link in the Air Force's logistics support network. AGMC's mission is to serve as the single depot repair agency within the Air Force for both missile and aircraft inertial equipment. Although primarily concerned with work of Air Force origin, AGMC also handles work from the other Military Services. An important portion of AGMC's work load is the repair of the Minuteman III Missile Guidance Set (MGS).

The importance of maintaining strategic missile operational capability dictates that AGMC be able to cope with current MGS work loads and to absorb changing work loads. For example, the present average input rate of repairable MGSs to AGMC is fairly constant (9). If the average input rate were to increase due to changing mission requirements, the Air Force could well have a repair capacity constraint on an operational requirement. In such an event AGMC managers would have to estimate what extra resources should be committed to MGS repair. Currently, there is no reliable method to render such estimates (9).

This study will attempt to develop a valid method for estimating what additional test/handling equipment and repair technicians would be needed for increased input rates to the Minuteman III MGS repair process.

Terminology

Because of the complex nature of the MGS repair process and the many technical terms associated with both the MGS and the repair process, the authors have inserted definitions throughout the thesis. Through definition and repetition of terms the authors hope to guide the reader through the complex and often confusing terminology that is an inevitable part of any technical discussion. Terminology given will be for the purposes of this thesis and is not necessarily applicable to other studies.

MGS. The abbreviation MGS for purposes of this thesis refers to the Minuteman III Missile Guidance Set.

Inertial Guidance System Repair Process. Genet has identified the depot level repair of inertial guidance systems as one of the most complex large-scale repair processes in existence. This complexity in repair is caused by the multi-level nature of the MGS. There are usually at least three distinct levels: the system level (MGS), the major subsystem level (computer, gyro stabilized platform, etc.), and the component level (module boards, accelerometers, etc.) (8:1). See Figure 1 on page 11. As a result, the MGS depot level repair process includes different

subprocesses at different levels of repair. For example, a faulty Gyro Stabilized Platform (GSP) is removed from the MGS at the first level of repair. The GSP then enters its own repair process at the second level of repair. If, to continue the example, an accelerometer in the GSP is found to have malfunctioned, the accelerometer is removed from the GSP and is then entered into its own repair process at the component (third) level of repair. A degree of dependency between the levels of repair does exist because the higher levels of repair are dependent on the lower levels for serviceable subsystems and components (8:1-3). A detailed discussion of the MGS repair process is available in Chapter II.

Repair Line. The repair line is the sequence of events undergone by the MGS, or one of its subassemblies or components, as it flows through its repair process.

Repair Operation. Repair operation refers to the technical operation that takes place at the repair station on the repair line.

Repair Station. The repair station is the point on the repair line where the repair resources of MGS test/handling equipment and repair technicians come together to perform a repair operation. For example, MGS test/handling equipment is used by the repair technicians at the diagnostic test station to accomplish the repair operation of diagnostic testing.

Repair Capacity. Repair capacity is the maximum work load that a repair resource can process.

Repair Resources. Repair resources are the test/handling equipment and repair technicians that perform the MGS repair operations.

Queue. Queue refers to a waiting line that develops when the work load at a repair station exceeds the repair station's capacity.

Decoupling Inventories. Decoupling inventories are stocks at major points in a production (or repair) line that make it possible to carry on each of the major activities relatively independently of each other (3:17-21). These inventories tend to reduce the dependence of one activity on the other. For example, if, as in the case of a MGS, Instrument X were removed from a higher-level assembly and sent to another shop for repair, the higher-level assembly could not be repaired until a serviceable instrument X became available. However, by having spare serviceable items available--by means of a "decoupling" inventory--the repair of the higher-level assembly could be accomplished without delay.

Service Level. A service level specifies that average inventory stockouts not exceed a certain percentage of demands (orders) received (3:24). For example, if management were to specify a ninety-seven percent service level, they would expect that, on the average, demands on

inventory would be filled immediately ninety-seven percent of the time. Conversely, an inventory stockout condition with no assets available for issue should occur less than three percent of the time on the average.

Recycles. The term "recycle" as it applies to a complex repair process is the return of the repaired item from some stage in the repair process to some earlier stage because of an unsatisfactory condition found at the later stage (6:2).

Activity. For purposes of the simulation model, an activity consists of either a repair operation or a transfer.

Transfer. Transfer refers to the movement of the item of interest between repair operations.

Transfer Fraction. Transfer fraction refers to the fraction of time that items subject to the transfer are to randomly move to a specified repair operation. For example, Activity 6 which is a transfer occurs with a mean rate of .5, therefore, fifty percent of all output from Activity 5 will on the average be transferred by Activity 6 to Activity 8. The remaining output of Activity 5 "falls through" Activity 6 to 7.

Repair Resource Utility. For purposes of the research effort, utility refers to the utilization of the repair resource as a percentage of its repair capacity. For example, a utility of fifty percent would indicate that

a repair resource was operating at one-half capacity, whereas a utility of 100 percent would indicate the repair resource was working at full capacity.

Justification for the Research

With the ever-increasing attention being placed on Department of Defense expenditures by Congress and the American public, it is important to find methods of reducing costs in all areas and at all levels of operations. Justification for the planned research rests upon the need for a method to accurately estimate additional resource requirements for an increasing work load. For it is only through the effective and efficient allocation of repair resources that the MGS depot level repair expenditures can be minimized.

Further justification rests with management's general need for information pertaining to repair resource requirements generated by an increased work load. The increase in work load could be the result of wartime surge conditions, such as occurred during the Vietnam Conflict, an increase in weapon system deployment rate or a decrease in the system's mean-time-between-failures (9). In any event, the maintenance of a strong defense posture by the United States requires that the depot repair facilities be capable of meeting programmed and unprogrammed increases in work load. Management support for the research topic has

been obtained from Mr. Russel Genet, Mr. Robert Hurst and Captain Paul G. Hansen (9; 10; 11).

Scope of the Research

The research involves the building, validating and exercising of a simulation model of the Minuteman III MGS repair process. The model simulates the system level repair process for the MGS and the subsystem level repair process for the gyro stabilized platform. Because of the model's complexity and the limitations of time, simulation of other subsystem or component repair processes were not attempted. The model is only concerned with the repair resources of test/handling equipment and repair technicians. No attempt was made to determine adequacy of floor space and utilities.

Objectives of the Research

The research objectives were, first, to build a simulation of the MGS repair process that very closely approximated the "real world" situation in existence at AGMC. Once the simulation model had been validated (tested to ensure it reflected the actual MGS repair process), the simulation model was used to investigate the following specific research objectives.

1. Determine what additional repair resources were required at various increased MGS input rates.

2. Determine which Depot Replacement Unit (DRU)[1] decoupling inventories were adequate at various increased MGS input rates. The adequacy of present decoupling inventory stocks in terms of "days of supply" was determined by comparing inventory requirements at the increased work load with present AGMC stocks.

3. Determine the effect of a reduced recycle rate on repair resource requirements at the normal average MGS input rate. The possibility presently exists that an alternative approach to increasing the repair capacity of the MGS repair process would be through the reduction of repair recycling, rather than the addition of more repair resources. If it were possible to show through simulation that a twenty-five percent reduction in recycling were equivalent to a specified amount of addition repair resources, AGMC would have a basis for determining whether it would be more cost effective to reduce the recycle rate or to add repair resources.

Research Hypothesis

A simulation model of the MGS repair process can be developed that reflects the actual MGS repair process at AGMC.

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[1] A Depot Replaceable Unit (DRU) is a component or subassembly which can only be removed from a higher assembly at the depot.

Research Questions

After the MGS repair process model has been validated to ensure it reflects the actual MGS repair process it will be used to answer the following research questions:

1. For increased average MGS input rates, what additional repair resources are required?

2. For increased average MGS input rates, which Depot Replaceable Unit (DRU) decoupling inventories have adequate assets?[2]

3. For the normal average MGS input rate, what effect does a twenty-five percent reduction in the repair recycling rate have on repair capacity requirements?

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[2]For purposes of this thesis, DRU decoupling inventory assets were considered to be adequate if there was sufficient stock-on-hand to support the MGS repair process for a minimum of five days. The selection of five day minimum for stock-on-hand agrees closely with what Mr. Hurst of AGMC deems adequate (11).

CHAPTER II

THE MISSILE GUIDANCE SET REPAIR PROCESS AND RELATED CONCEPTS

The purpose of this chapter is to provide an overview of the MGS repair process and a brief discussion of subjects relevant to a complex repair process.

Missile Guidance Set Description

The Missile Guidance Set (MGS), when installed, is located above the third stage of the missile and contains the airborne equipment used for flight. The purpose of the MGS is to place the missile on a ballistic trajectory that would impact a designated target. To perform its function, the MGS evaluates flight information and correlates it to target data, determines deviations from desired flight path, and sends flight correctional information to the flight control system (18:iii-v).

As an assembly, the MGS is very complicated and employs some of the most advanced technological concepts which in turn demand exacting repair skills and standards (8:1-4). The MGS has several levels of assembly. At the highest level, the system level, the MGS is comprised of the body, cabling and five major subsystems, as illustrated in Figure 1. The five major subsystems make up the

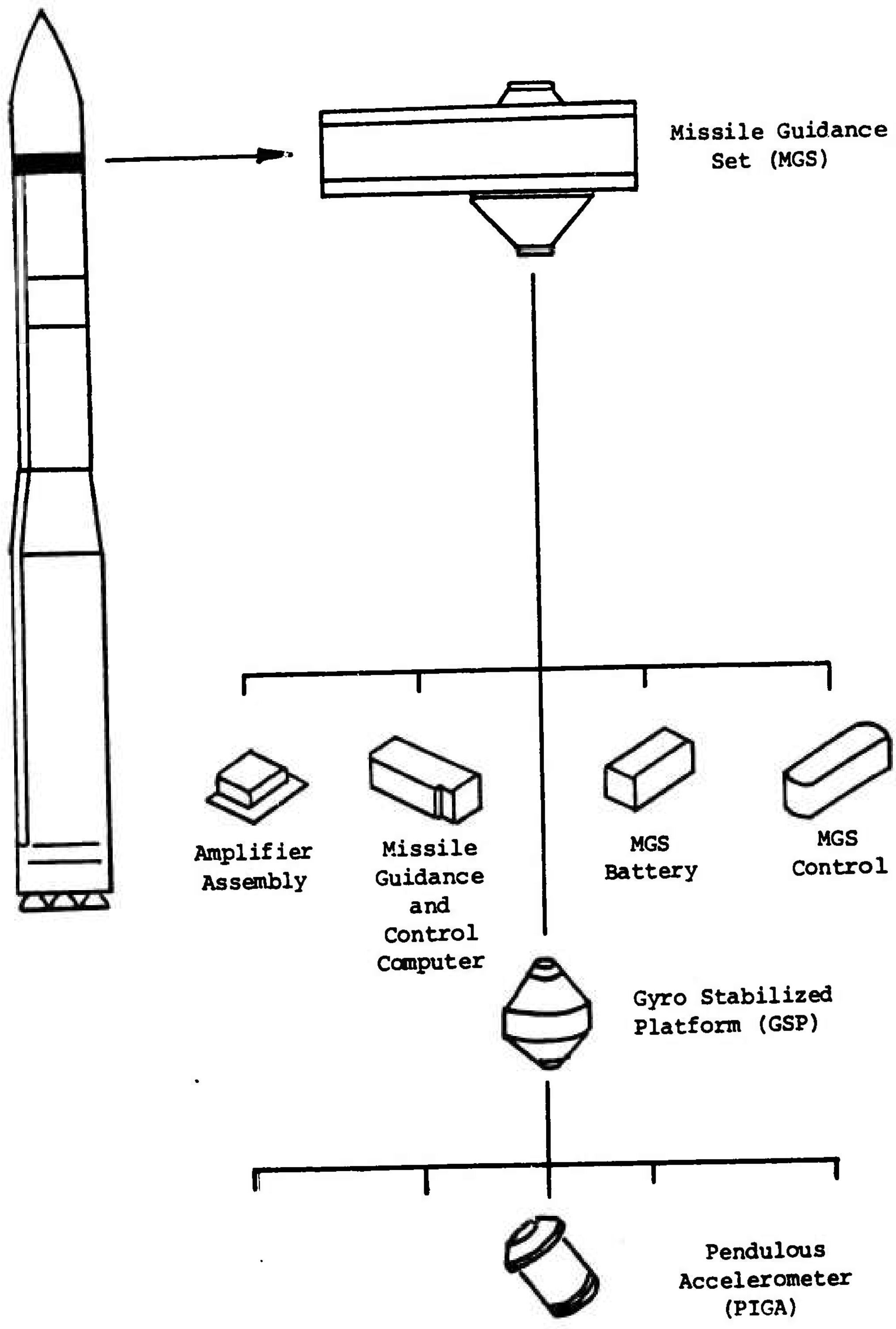

Figure 1. Missile Guidance Set Major Components

subsystem level and the components within the subassemblies, such as the PIGA, make up the component level.

Overview of the Missile Guidance Set Repair Process

When the MGS malfunctions it is removed from the missile, packed into a specially designed container and shipped to AGMC, Newark AFS, for repair. AGMC is responsible for all levels of repair on the MGS. This means that AGMC is not only responsible for returning serviceable MGSs to the field but also for the repair of all lower level assemblies and components within the MGS (9; 11).

The repair of a MGS primarily involves the use of men, equipment, materials and information, organized into repair lines. Within each level of assembly, from the MGS down, there are repairable subsystems and components each of which is processed through its respective repair line.

In essence, a repair line is comprised of repair stations which perform repair operations on MGS systems, subsystems, and components. Repair lines are also given some semblance of independence from each other by the provision of decoupling inventories, even though they are always interdependent in the long run (8:1-4).

Repair operations are tasks that may be performed on a repairable item from the time it first enters the repair process to the completion of final testing for serviceability. Although all components, e.g., GSP, would

undergo some repair operations, not all operations are performed for every component repaired. On the other hand, some operations are repeated several times, often unnecessarily. Such repetitions are known as recycling which will be discussed later on in this chapter. Typical operations are: malfunction verification, removal of failed part, selection of a serviceable part from the decoupling inventory, installation of the serviceable part and functional test.

As illustrated in Figure 1, the MGS contains five major subsystems each of which is repaired (when needed) independently of the MGS. During repair of these subsystems other components are removed and replaced, which in turn are repaired independently of their higher level assembly. As an example, at the first level of assembly (and repair), the GSP may be found faulty and removed from the MGS. During repair of the GSP (second level) the Pendulous Integrating Gyroscopic Accelerometer (PIGA) may be replaced. The PIGA would then be repaired at the third level during which other components might be replaced and sent to yet a fourth level of repair. Similar levels of assembly and repair exist for the other subsystems of the MGS. Brief descriptions of the MGS and GSP repair lines follow.

MGS Repair Line

In the repair of a MGS some twenty basic repair operations may be performed. The process starts with receipt of the unserviceable MGS and ends with stage-out and shipment of a serviceable MGS. After receipt and before actual repair work can begin, specific documents have to be initiated to accompany the MGS throughout repair. This operation is referred to as data acquisition, and one important part is to obtain details of past repairs on the MGS from a computer record. Subsequent repair operations can be broadly categorized as diagnostic checks, repair, remove and replace, or performance tests. Table 1 lists all MGS repair operations. Each is numbered so that it can be related to the associated flow diagram of the process given in Figure 2.

As may be seen in Table 1, several remove and replace operations exist. The one of importance here is Number 21, Remove and Replace the GSP. The mechanics of a remove and replace operation are not so simple as might be implied by Table 1. By referring to Figure 3 it may be seen that the removed GSP is sent to its repair line (second level) and that a serviceable GSP, if there is one, is taken from the decoupling inventory and installed in the MGS. If the decoupling inventory is empty, i.e., there is no serviceable GSP to install, the MGS is removed from the repair line and put into an awaiting-parts holding area.

TABLE 1

MGS REPAIR LINE OPERATIONS

REPAIR OPERATIONS	
Activity Number*	Description
1	Preparation
2	Stage-in, Data Acquisition
3	Malfunction Verification/Diagnostics
5	Repair DC-2
7	DITMCO--Wire Harness Check
9	Inspect and Repair Shields
11	Overstress Check
13	Refurbish Parts
15	Remove and Replace B.W. Harness
17	Remove and Replace Trans. Detector
19	Remove and Replace P-92 Control Box
21	Remove and Replace GSP
23	Remove and Replace D-37D
25	Remove and Replace MGS Computer
27	Repair B.W. Harness
28	Functional Test
31	Performance Test
34	Wing V Bias
35	Stage-out and Minor Repair
36	Ship

*Numbers are Activity Numbers of repair operations. Intermediate numbers are other activities comprised of transfers. Therefore, activities are comprised of repair operations and transfers.

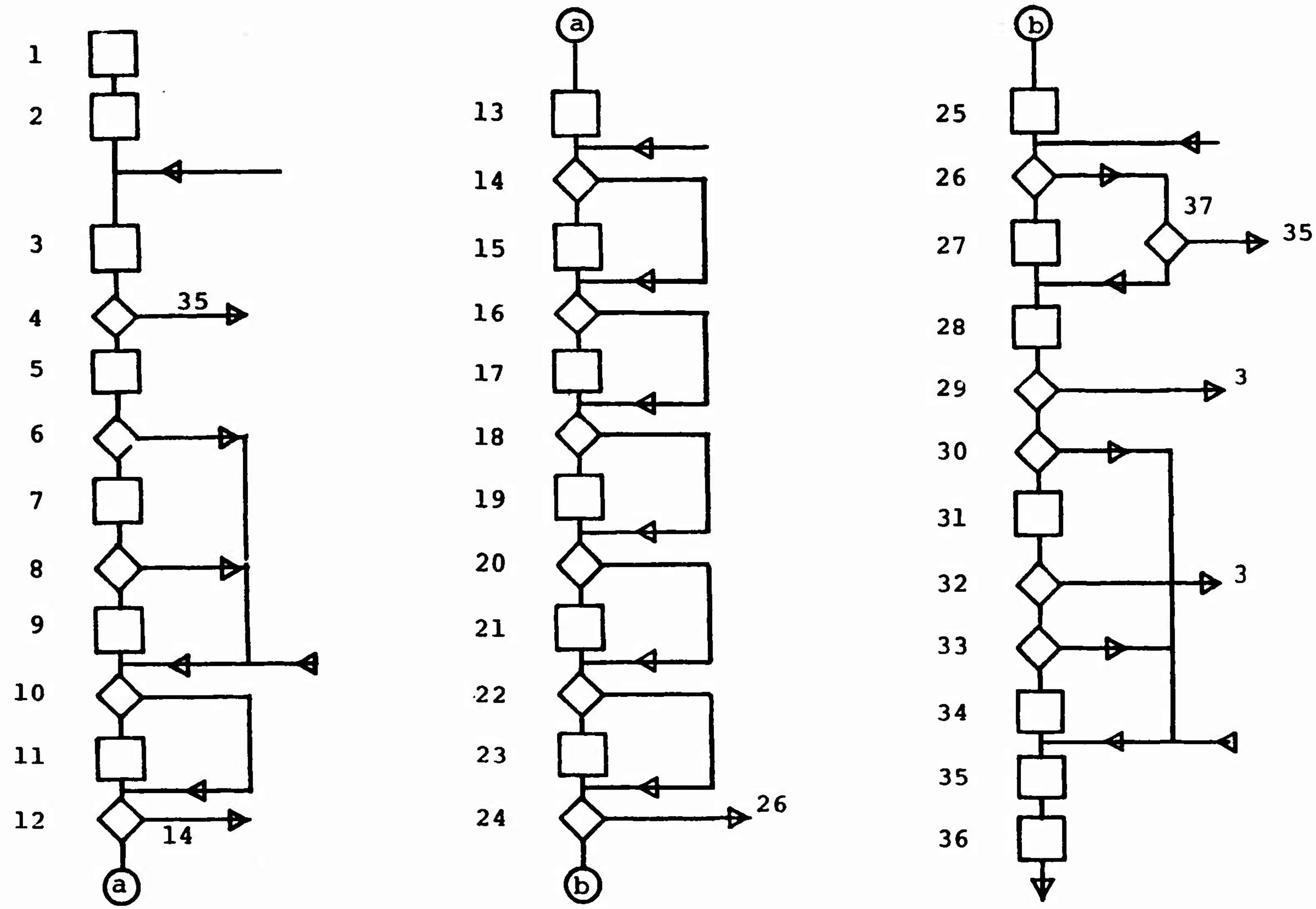

Figure 2. MGS Repair Flow Diagram

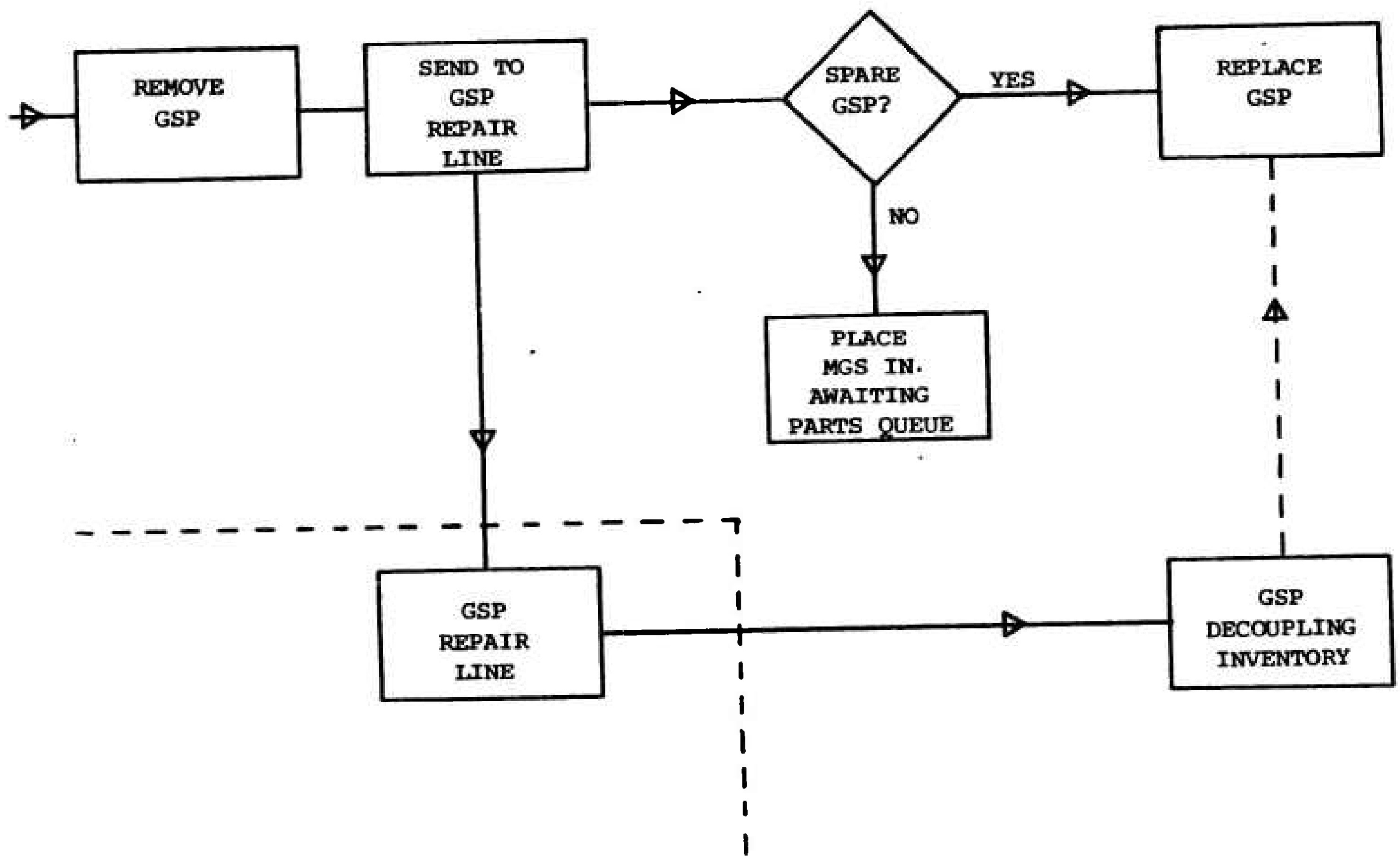

Figure 3. Remove and Replace GSP

Once the GSP repair line produces a serviceable GSP, it is installed in the waiting MGS. The MGS can then be put back into the repair line, normally at the point from which it was withdrawn.

The purpose of Figure 2 is to show the flow of work and the interdependence of operations. The following features of a typical repair line can be seen on the diagram: (1) serial flow, e.g., operations 1 through 3 are performed sequentially; (2) parallel flow, e.g., operations 14 through 23 which can be performed independently; (3) bypassing certain operations, e.g., operations 5 and 13 are not always performed on every MGS; and (4) feedback (recycling), e.g., MGS failing tests of operations 28 and 31 and being returned to the repair line at operation 3.

GSP Repair Line

A description of the GSP repair line would be almost identical to that just given for the MGS and therefore will not be repeated here. However, the appropriate table and operations and flow diagram are given in Table 2 and Figure 4 on the following pages. Also as was done for the MGS, Figure 5 shows in more detail what is happening at GSP repair operation number 70, Remove and Replace the PIGA.

Related Concepts

To illustrate the scope of the problem, several maintenance concepts need to be briefly reviewed. These

TABLE 2

GSP REPAIR LINE OPERATIONS

REPAIR OPERATIONS	
Activity Number	Description
51	Stage-in
52	Data Acquisition
54	Malfunction Verification/Diagnostics
55	Remove Housing
56	Remove Shrouds
58	Minor Repairs
60	Modify B.W. Harness (TCTO-607)
61	Open Functional Test
62	R and R* Electronic Modules
64	Change I.D. Plate
66	R and R Torque Motor
68	R and R Gyro
70	R and R PIGA
72	R and R GCA
74	R and R Normal Resolver
76	R and R Thermistor
78	R and R Cable Plug
80	Screen Modules (TCTO-668)
82	Repair Housings and Access Covers
84	Refurbish Parts
86	Repair Axis and Wire Harness
88	R and R Alignment Block
90	Relieve Cable Tension
92	DITMCO Wire Harness
94	Open Function of Repair Verification
96	Fine Balance

*R and R is Remove and Replace.

TABLE 2--Continued

REPAIR OPERATIONS	
Activity Number	Description
97	Clean, Inspect, Replace Housings
99	Fine Balance
100	Install Housings
101	Pre-Vibration Test
103	Vibration Test
105	Post-Vibration Test
107	Performance Test
110	Wing V Bias
112	Purge, Full and Leak Test
114	Repair Leaks
115	Stage-out

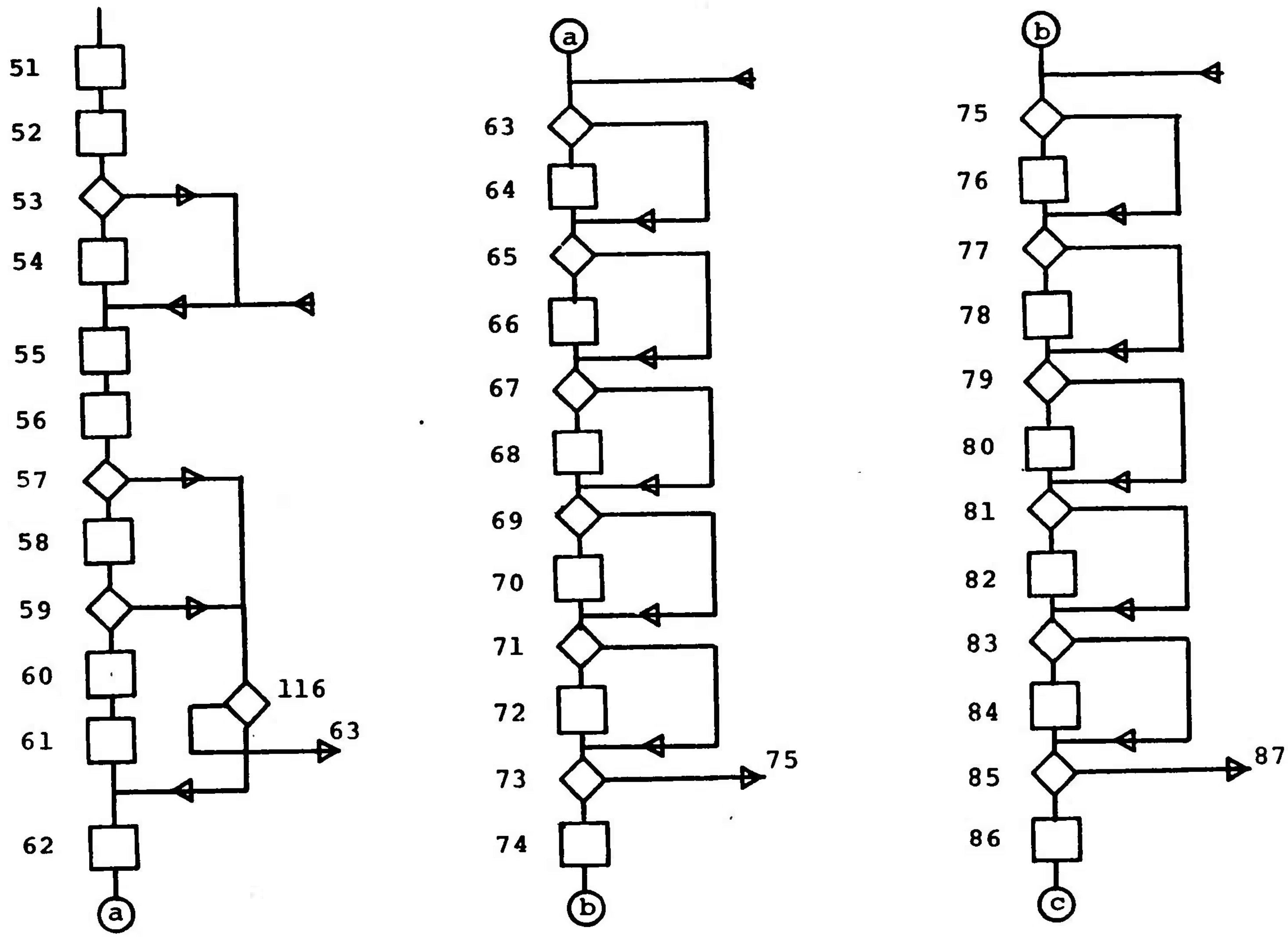

Figure 4. GSP Repair Flow Diagram

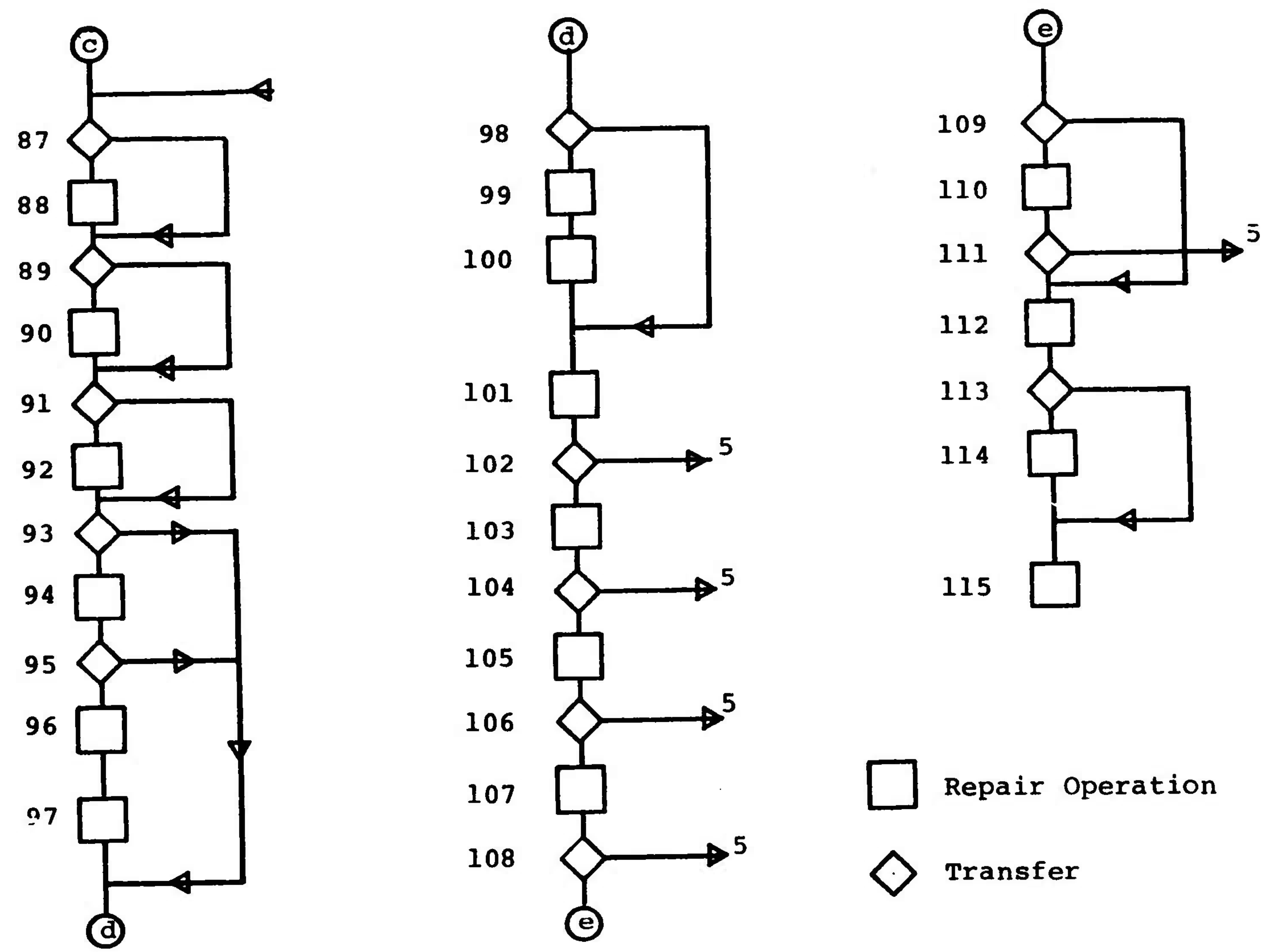

Figure 4. GSP Repair Flow Diagram--<u>Continued</u>

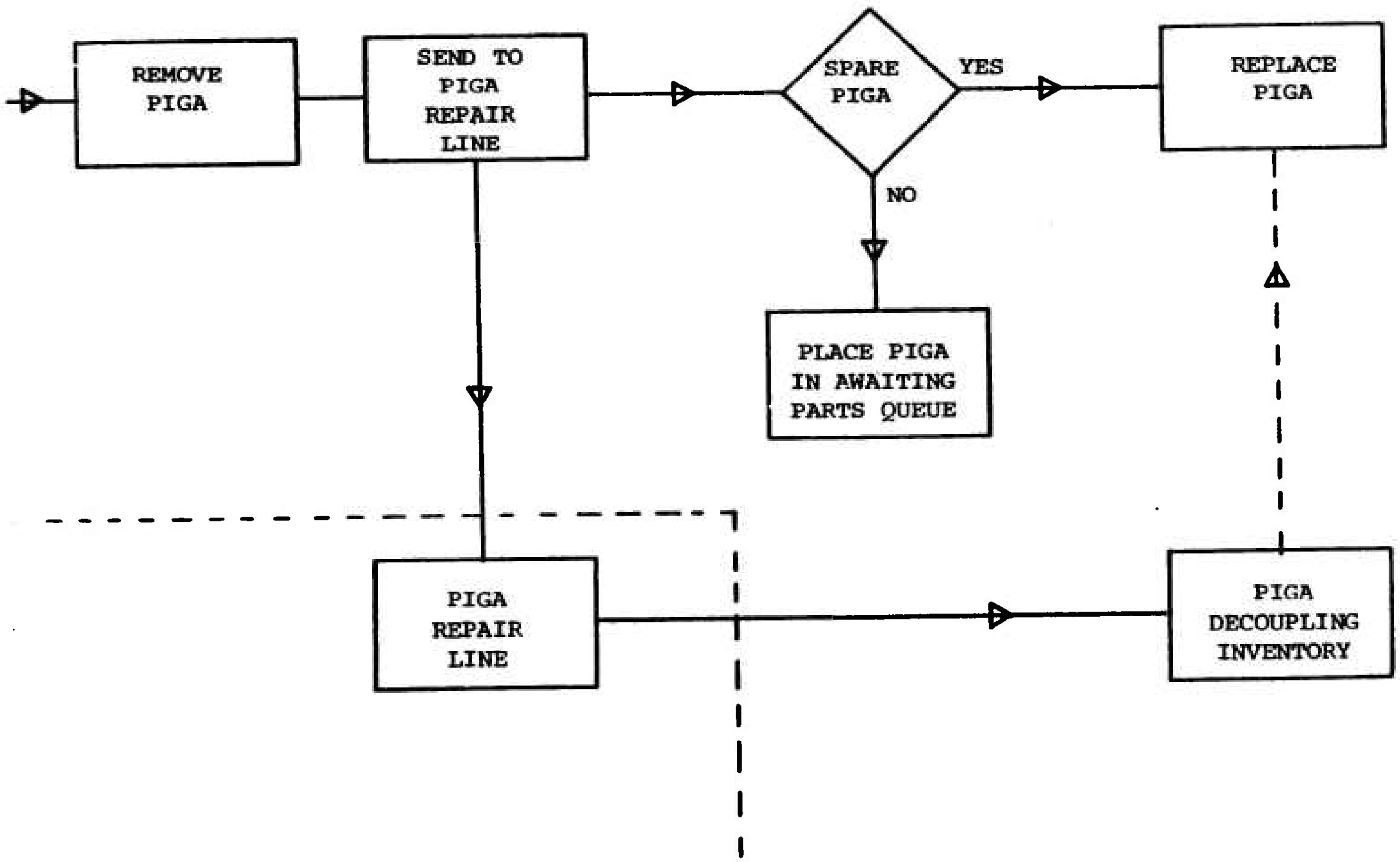

Figure 5. Remove and Replace PIGA

are: (1) reliability, of which MGS input rate is a function; (2) repair resources such as shift-work, overtime and decoupling inventories; and (3) repair recycling.

Reliability

For purposes of this thesis the examination of reliability theory was limited to its application to mature weapon system maintenance and complex depot level repair processes. Hansen has described a mature weapon system as one for which major acquisition is complete and for which extensive data on reliability is available (10).

The objective of a weapon system reliability program is to extend the life of the equipment to the maximum extent possible with due consideration to cost and other pertinent factors. The measurement of individual items of equipment reliability is expressed as mean-time-between failures (MTBF) (1:22).

Recent research has shown that in a complex depot level repair process the reliability of the system being repaired is dependent on the reliability of the repair parts used (4:28-30). In essence, the total reliability of a system may be assumed to be dependent upon the reliability of each and every part (8:25).

The human influence on reliability also needs to be considered when examining any maintenance activity. Pieruschka sees the avoidance of human errors during

maintenance as the most difficult problem in the attainment of highly reliable complex equipment (15:344).

A third influence on reliability that requires consideration is that of test validity. Genet has identified the return to service of an item that is in fact unserviceable as the end result of invalid testing (6:1-8).

The mean-time-between failures is important to the problem because it is a direct measure of the system reliability which, when applied to the MGS, influences the input rate to AGMC. A decrease in reliability means an increase in repair input. For a mature subsystem such as a MGS, the reliability is a function of repair skill, component reliability and test validity (10). A decrease in any of the three would increase AGMC's work, thereby capturing resources that would otherwise be used to cope with programmed increases in MGS input.

Shift-work and Overtime

With respect to the stated problem, overtime and then shift-work are the first "lines of defense" when work load (input) exceeds the normal workday capacity of equipment (13:5-8). Increased capacity would be gained by operating equipment twenty-four hours a day and either adding another shift of workers or splitting the third shift as overtime for the existing shifts of workers. Alternatively, weekend operation with overtime is available. However, work-force overtime limitations and repair

equipment maintenance may limit the excess capacity to less than what is potentially available.

The ultimate importance of shift-work and overtime to the problem of increased work loads is that both are a means of buying time while more permanent arrangements are made to handle the increased work load (11).

Decoupling Inventories

Of the differing functions performed by inventories, that of decoupling inventories is of the greatest interest in a complex repair process (11). Decoupling inventories are stocks at major points in a production (or repair) line that make it possible to carry on each of the major activities relatively independently of each other (3:17-21). Buffa and Taubert found these stocks are necessary because of the uncertainties of demand at that point. The variability of demand means in effect that larger inventories must be carried to provide for the possibility of larger than average demand. Another uncertainty affecting decoupling inventory size determination is that of supply lead time (3:17,95).

Within a complex repair process decoupling inventories tend to reduce the dependence of one activity on the other (3:17-21). To repeat a previous example, if, as in the case of a MGS, instrument X were removed from a higher-level assembly and sent to another shop for repair, the higher-level assembly could not be repaired until a

serviceable instrument X became available. However, by having spare serviceable items available--by means of a "decoupling" inventory--the repair of the higher-level assembly could be accomplished without delay. Nonetheless, the degree of independence achieved is limited in that the entire production process may be shut down, in time, because of a stock-out condition at one of the decoupling inventory stock points (3:20).

When establishing inventories there are certain tradeoffs the manager must take. England and Leenders have stated that in the case of decoupling inventories the amounts and locations of the inventories are dependent on the relative advantages of increased flexibility in operations over the costs of maintaining the inventories. Inventory carrying cost comprises those costs associated with handling, storage, etc., and stock-out costs are the costs to the organization of not having the required inventory items on hand when needed (5:359-371). Therefore, for decoupling inventories the tradeoffs center around consideration of inventory carrying cost versus stock-out cost.

Because of the difficulty in isolating realistic stock-out costs, management developed the service level concept which specifies that average stock-outs not exceed a certain percentage of the demands received (5:379). Mr. Robert Hurst of AGMC suggests a service level of

ninety-seven percent be used to establish decoupling inventory levels in the MGS repair process (11).

Correct decoupling inventory stock size is of critical importance in a complex repair process such as the MGS (11). A stock-out condition at one of the decoupling inventories may cause, in time, a shutdown of the entire process (3:20). Buffa and Taubert identify two methods of determining inventory size in conjunction with a predetermined service level. In the first case, supply lead time is held constant while demand is allowed to fluctuate, while in the second case, both demand and supply lead time are treated as variables (3:96-98). In the second case, an analysis of both demand and supply lead time distributions is necessary in order to construct a joint probability distribution of demand during lead time. To reduce the computational work load the distribution can be developed by sampling and the stock levels can be determined by simulation (3:106-110).

Recycles

The term "recycle" as it applies to a complex repair process is the return of the repaired item from some stage in the repair process to some earlier stage because of an unsatisfactory condition found at the later stage. Recycles can be very expensive and wasteful in terms of materials and manpower. For example, when an error occurs early in the repair process, but is not detected until near

the end of the process, the item must repeat not only the stages of error and detection, but all intervening stages in the process as well (6:2; 12:19).

Genet was able to determine the types of errors that are most costly in terms of recycles through the development of a complex computer model of a single repair process. He found that about fifty percent of the cost of the repair process was due to either build errors or test errors. When broken down his findings showed that approximately thirty percent of the cost of repair was due to recycles that resulted from decision errors related to diagnostic or functional tests. The decision errors were a result of either human error or invalid test results (6:3). Similar tests using a different computer program and different techniques on the KT-73 Inertial Measurement Unit repair process determined that total repeated or "recycled" work may constitute as much as 39.9 percent of the average variable cost of repair (12:97).

The concept of criticality applies to the identification of those few areas of a complex system that cause the majority of the problems (7:4). These are the critical points where a slight improvement in the problem situation would result in a major improvement in the system process (7:4). Using a computer model of the KT-73 Inertial Measurement Unit repair process, Iwerson, et al., were

able to identify those critical paths, which, if improved, could result in substantial cost reductions (12:100,101).

Assuming that the same effect exists in the MGSs, recycling would absorb time and funds that could otherwise be used to handle a larger throughput.

CHAPTER III

SIMULATION MODEL DEVELOPMENT

The vehicle for the proposed research was a computer simulation model of the MGS repair process. The chapter begins with a theoretical discussion of modeling and simulation, and is followed by a brief overview of the available types of computer simulation languages. The chapter ends with a discussion of the MGS repair process simulation design.

Modeling and Simulation

"A model is a representation of an object, system, or idea in some form other than that of the entity itself [17:4]." Models have always played an important role in man's development. They help to conceptualize and communicate; they have proved of great value to training and instruction; and in the field of research, they aid in experimentation and act as tools of prediction (17:5). Models often find ready application in research and experimentation due to either practical or economic feasibility (17:6).

Many different types of models exist. One classification used by Shannon is over a spectrum from exactness

to abstraction. Classifications are physical models at the exactness end of the spectrum, through scaled models, analog models, management games, computer simulation, to mathematical models at the abstract end (17:8). Shannon has found that for some classes of problems, such as the representation of a complex repair process, computer simulation is a more viable proposition. For example, for the so-called input/output models that have to be "run" rather than "solved" simulation is better (17:10). Where the dynamic changes over time are important, simulation has a place. ". . . a model is just a model until we advance it through time; then it is simulation [2:74]."

Although computer simulation is often the most appropriate approach, often the only method, and often the "intuitively appealing" approach to a problem, it is not without its disadvantages. For example, good simulation can be expensive; a simulation can appear to be valid and yet not be; and simulation suffers from imprecision, the extent of which cannot be measured (17:13).

According to Shannon, the art of modeling is the process of analysis, abstraction, and assumption to characterize the system being modeled, followed by enrichment and elaboration of the model until a useful approximation is obtained. A good simulation model also has desirable properties such as being simple to understand, goal directed and adaptive (17:20,22).

The simulation process generally follows the systems approach to problem solving, from systems definition through to implementation and documentation (17:23). However, unlike approaches to some other problems, simulators have to be evaluated before they are of any use. Evaluation is the process of: (1) verification, seeing that the model behaves as intended; (2) validation, seeing that the model behaves like the real world it is simulating; and (3) problem analysis, which is the interpretation of results of the model (17:210).

Simulation Languages

Simply deciding that computer simulation is appropriate to the proposed research is not enough. Selection of the computer language to be used can have important ramifications. Theoretically, a simulation model could be programmed in any language but, just as there were major classes of problems that led to problem-oriented languages (COBOL, FORTRAN and others), so are there different kinds of modeling problems for which appropriate simulation languages have been developed. Some of the most common simulation languages are SIMSCRIPT, GASP, DYNAMO and GPSS (17:12-140).

SIMSCRIPT is one of the special purpose, discrete change simulation, event oriented languages. It is widely used and, according to the results of a user survey reported

by Shannon, is rated first as a preferred language, and rated very well for capability and ease of use (17:140). SIMSCRIPT is usable on a wide range of computers and is the subject of a great deal of literature (17:131).

Like SIMSCRIPT, GASP is also a special purpose, discrete change simulation, event oriented language. In the user survey reported by Shannon, GASP is rated lower than SIMSCRIPT and GPSS for capability and preference, but is rated about the same as SIMSCRIPT for ease of use (17:140). Although a simulation language, GASP is FORTRAN based and, therefore, can normally be used on any machine for which a FORTRAN IV compiler is available (17:131).

DYNAMO is a continuous change simulation language which is used when the correct simulation of the effects of instantaneous rates of change within the system is needed. In a simulation situation where events occur in discrete intervals and time is not of continuous interest, DYNAMO is not suitable (17:131).

"GPSS (General Purpose Simulation System) is a simulation programming language used to build computer models for discrete-event simulations [16:vii]." IBM first developed GPSS in the late Fifties and has since developed it to the version known as GPSS V. Different versions of GPSS are in use and available for use on several different brand name computers. As a language, GPSS offers simplicity in use, programming convenience, and service as "a vehicle

for concept articulation [16:vii]." The language derives its simplicity from a block diagram/flowcharting technique of constructing models, and it incorporates convenient features for the automatic production of statistical reports (16:vii). Thomas A. Schriber's text, Simulation Using GPSS explains the language well and in considerable detail.

MGS Repair Process Simulation Design

Selection of a Simulation Language

Basically the selection of a simulation language is dependent on two sets of criteria: the first set deals with the selected model and the situation to be simulated; the second set is made up of the analyst's preferences and the existing work situation. From among the simulation languages that meet the first set of criteria, the analyst selects a language that meets his needs in the existing circumstances.

In simulation terminology, a transaction flow model incorporates the characteristics that can be found in the MGS and GSP repair processes. These characteristics form the criteria against which the simulation language is measured and are as follows: (1) items (transactions) upon which repair operations are performed are discrete, that is, each operation is a single event; (2) items are either being worked on, in transit or waiting in a queue; (3) transactions are inanimate and therefore do not have

the facility to choose, e.g., whether to stay in the queue or not; and (4) a repair process is an open-loop system, not a closed-loop, dynamic system. (5) Although the transactions and operations in the MGS repair process are relatively simple, operations are numerous.

The first conclusion possible from the preceding criteria is that the chosen simulation language should be a special language that can do the job and, yet, be simple enough to minimize the sheer programming effort that would otherwise be needed for the simulation of so many operations.

Because DYNAMO was designed to simulate dynamic, closed-loop systems which are characterized by continuous change, it was therefore unsuitable for the simulation. Each of the remaining three languages, SIMSCRIPT, GASP and GPSS were capable of doing the job.

Once the simulation language selection was narrowed down to those languages that could do the job, the remaining languages were measured against the second set of criteria. The criteria composed of the circumstances surrounding the situation and the analyst's preferences are as follows: (1) computer capacity and running time are not constraints; (2) the intended user was unfamiliar with any simulation language and was a student under a time constraint. Therefore, the overriding constraint was the need for minimum learning effort and simplicity. Although SIMSCRIPT and

GASP are both powerful languages and often preferred by professionals in computer simulation GPSS is noted by Shannon for its ease of learning and simplicity in use (17:140).

Because of its simplicity and ease of learning, GPSS was used for the model of the MGS repair process. Its suitability for a repair process model has already been demonstrated (20:34).

Simulation Model Design

"The design for a computer simulation experiment is essentially a plan for purchasing a quantity of information . . . [17:144]." As for most other experiments, the resources for a given simulation are normally limited and therefore the tradeoff between the information available from a model, and the cost of getting it will be a function of the model design (17:144). However, cost and benefits are not always completely exchangeable. Most simulations would have a minimum objective and therefore a minimum cost involved. Only above the minimum requirement can tradeoffs take place. Therefore, at each step in the creation of the model, the designer should always be mindful of the objectives, and the costs of building, validating and making enough experimental runs from which to obtain valid data (17:208).

Initial design of the MGS repair process model identified several minimum required capabilities. In order

to meet the objectives of the research questions, the proposed model had to adequately simulate:

1. a multi-level repair process; i.e., the simulation of many repair lines concurrently;

2. two or more operations utilizing the one repair station (not concurrently);

3. up to three shifts per day per server, and for variable days per week;

4. variable decoupling inventories between different levels of repair; and

5. repair recycling.

A prototype model, incorporating all of the foregoing concepts was built, simulated and tested before any attempt was made to construct the overall model. To help illustrate the repair functions to be simulated, Figures 6, 7 and 8 show simplified diagrams of preceding submodels 1, 2 and 5 respectively.

A detailed technical explanation of the simulation model design and the computer program itself are contained in Appendices A through C.

The data required to build the model consisted primarily of repair operation frequency and repair transfer destinations for the MGSs processed. Repair times for each of the repair operations was also required for model development. A detailed description of the model-data base is presented in Chapter IV.

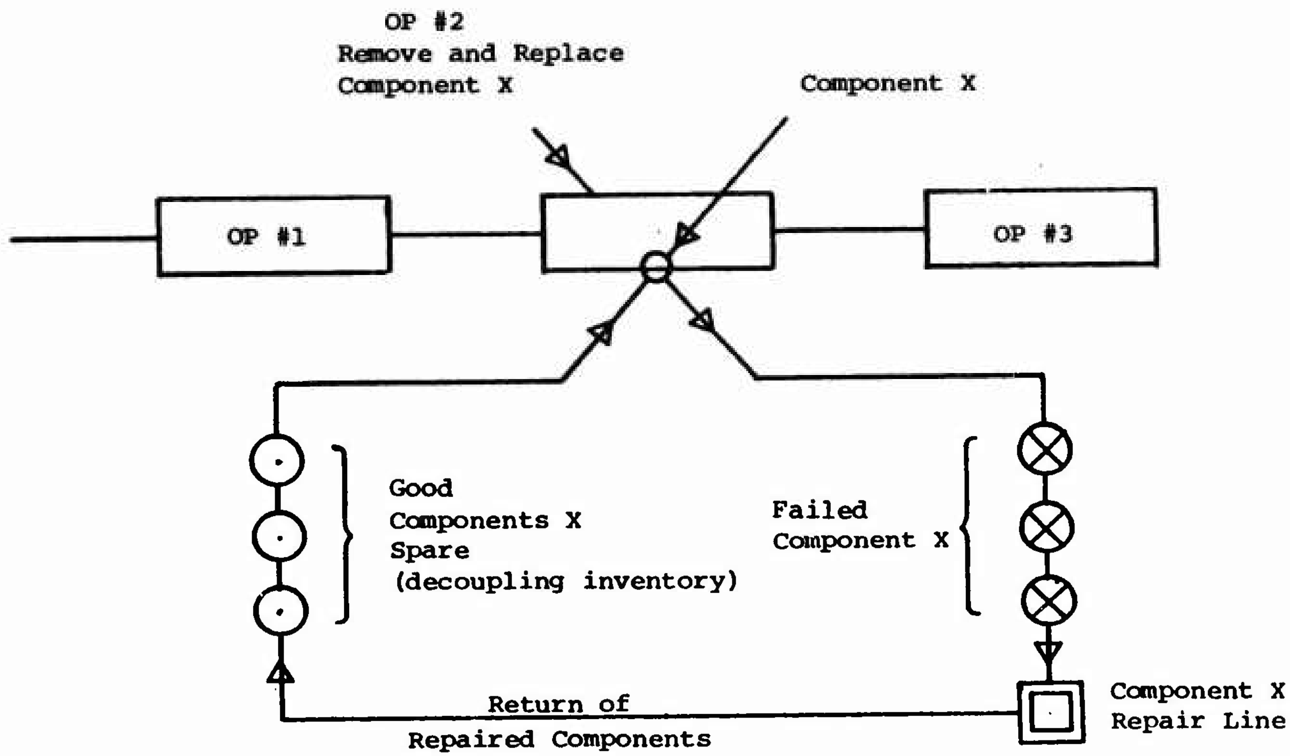

Figure 6. Multi-level Repair

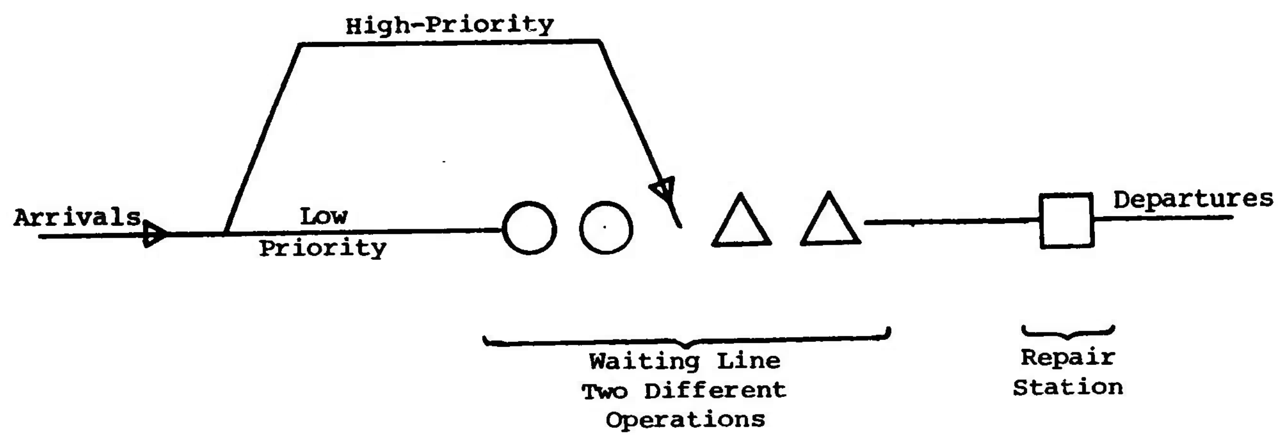

Figure 7. Two Operations--One Repair Station

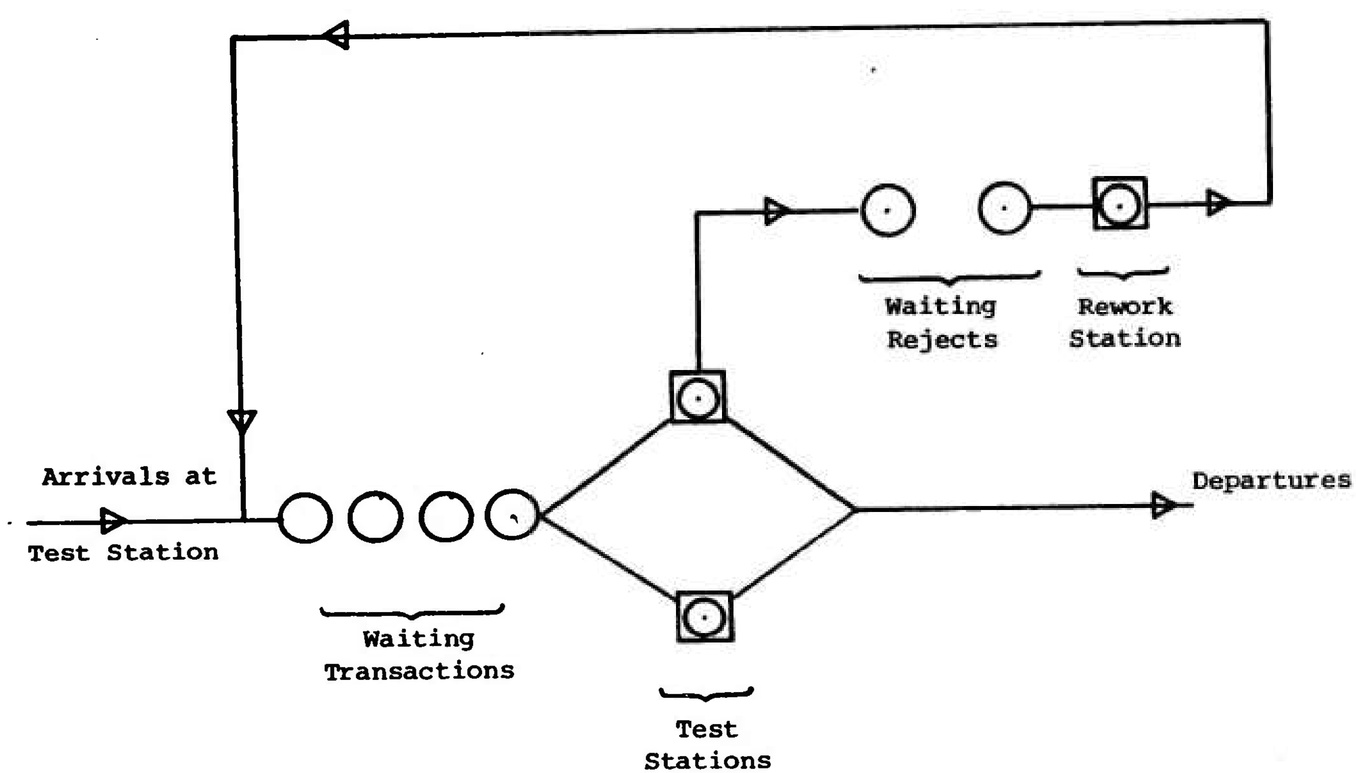

Figure 8. Repair Recycling

Assumptions

As previously stated in the discussion on modeling, any model is an abstraction of the real world made possible by the use of simplifying assumptions (17:20). The following general assumptions support the model developed by the authors.

1. A simulation model that reflects the real world in situations that can be validated will continue to reflect the real world in situations that cannot be validated. This assumption is basic to the use of the model as a predictive device.

2. Adequate floor space and utilities to accommodate the addition repair resources are available. It was not within the scope of the research to evaluate adequacy of floor space and utilities; but, rather, to present AGMC's management with information regarding the need for additional repair resources at a specified work load. AGMC's management can then determine how best to accommodate the addition repair resources.

3. Addition of repair resources to a repair station can occur immediately; i.e., the lead times on the supply of additional equipment and trained people are assumed to be zero. The preceding assumption can be safely made in the research because the object of the research was to predict the need for additional repair capacity, a

step that should always precede any assessment of supply or training lead times.

4. The practice of "cannibalization" does not exist. Cannibalization, when it exists, refers to the practice of removing a serviceable component from an unserviceable system and its subsequent installation in another unserviceable system to make the latter system serviceable (11). Simulation of the cannibalization process would seriously complicate the model and potential increases to model validity would not be worth the effort. Additionally, AGMC managers feel that the existence of actual cannibalization is so minimal that no benefit could be derived from including it in the model (9; 11).

CHAPTER IV

SIMULATION MODEL VALIDATION

This chapter presents the methodology used to validate the simulation model. It begins with a theoretical discussion of model validation, presents a thorough discussion of the model's data base and proceeds to an explanation of the methods used to logically test for support/no support of the research hypothesis.

Theoretical Discussion

"A model should only be created for a specific purpose, and its adequacy or validity evaluated only in terms of that purpose [17:208]." Before any model can be put to use the degree of confidence that a user has in its ability to predict needs to be established. Such an ability for prediction is a function of how well a model can replicate the problems and behavior of the system being simulated; or at least a replication of those system characteristics of interest to the research purpose (17:208).

Shannon includes validation within the process of model evaluation, along with the categories of verification and problem analysis. Verification is insuring that the model behaves as the experimentor intended, which is the same as establishing reliability. If the model is

reliable, it will replicate results reasonably consistently. However, reliability does not imply validity since results can be consistently false. Validation, therefore, follows verification and tests the agreement between the behavior of the model and that of the real system. Problem analysis deals with the interpretation of experimental results (17: 210).

The principal method of validating a computer simulator model is by "comparing the input-output transformations of the model to those of the real world system [17: 217]." However, Shannon points out that errors in design, programming, data, procedural use of model, and in interpretation of results, even when minimal, prevent a model from replicating the basic system exactly. In establishing validity, the researcher needs to perform statistical tests and seek expert opinion from participants in the real system being modeled. Only then can the researcher consider that he has a valid model with which to run experiments (17:216,217,227).

Data Underlying the Simulation Model

Simulation model validation actually has two dimensions, namely, the validity of the underlying data, and how closely the model itself reflects the real-world situation it is meant to represent. Because the data underlying the model came from numerous sources and was at times subject to certain qualifying assumptions, the data sources, the

choice of probability distributions, and the assumptions made about the data are presented in detail. By providing this detailed explanation the researchers hope to provide the reader enough information about the underlying data so that he can exercise his own judgement concerning its validity.

Primary Sources

The primary sources of data for the model were as follows:

a. MGS

1. Flow Diagram MM III System, 1 January 1975;

2. FY-75 Line Load and Personnel Equivalents, 18 April 1975.

b. GSP

1. Flow Diagram MM III Platform, 1 July 1974;

2. FY-75 Line Load and Personnel Equivalents, 21 April 1975.

For both the MGS and GSP repair lines the above documents were discussed with AGMC staff personnel and repair line managers to identify inconsistencies between the documents and actual operations. General corrections were needed, particularly to the Flow Diagram MM III Platform, 1 July 1974. Revised flow diagrams are given in Figure 2 and 4, pages 16 and 21 respectively. See Tables 3 and 4 for copies of Line Load and Personnel Equivalent lists that were used.

TABLE 3

FY-75 LINE LOAD AND PERSONNEL EQUIVALENTS 18 APR 75
NS20 SYSTEM TEST AND REPAIR

Operation	Process Hours	Man Hours	Occurrence Factor
RECEIVE SYS C&W	1.26	2.51	1.00
STAGE DATA ACQ	6.25	9.51	1.00
MAL VER DIAG	12.69	9.04	1.02
REMOVE GSP	1.62	3.23	0.73
REMOVE D37	0.68	0.68	0.93
REMOVE MGSC	0.37	0.37	0.41
REMOVE P-92	0.42	0.42	0.32
REMOVE TRANSDET	0.34	0.34	0.28
REMOVE BWH	3.21	5.42	0.28
REPAIR BWH	6.35	12.72	0.28
DITMCO BWH	3.22	6.19	0.52
REPAIR SHIELDS	0.00	1.02	2.55
REFURBISH PARTS	1.00	1.80	0.41
INSTALL BWH	6.24	10.07	0.28
INSTALL TRANSDET	0.45	0.45	0.29
INSTALL P-92	1.34	1.34	0.32
INSTALL MGSC	0.85	0.85	0.41
INSTALL D37	1.44	1.44	0.53
INSTALL GSP	1.02	2.00	0.73
FUNCT TEST	5.35	6.94	0.86
PERFORM TEST	34.71	23.90	0.56
WING V BIAS	9.70	7.13	0.25
STAGE OUT	4.45	3.21	1.00
SHIP SYSTEM C&W	5.37	5.93	1.00

Average Process Hours: 71.25

Average Manhours: 74.31

TABLE 4

FY-75 LINE LOAD AND PERSONNEL EQUIVALENTS 21 APR 75
NS20 GSP

Operation	Process Hours	Man Hours	Occurrence Factor
STAGE IN	1.84	1.84	1.00
MAL VER DIAG	8.54	8.54	0.77
RMV HSG	2.85	2.85	1.56
REMOVE PIGA	0.53	0.53	1.10
REMOVE GCA	1.01	1.01	0.83
REMOVE GYRO	0.40	0.40	0.81
REMOVE PLUG	1.35	1.35	0.20
REMOVE THERM	0.46	0.46	0.14
REMOVE TORQ MTR	1.02	1.02	0.01
R&R MODULE	1.70	1.70	1.00
AXIS REPAIR	47.11	47.11	0.04
MIN REPAIR	0.97	0.97	1.36
REFURB PARTS	1.00	1.00	0.72
REL CABLE TENS	6.09	6.09	0.02
MOD TCTO607	9.67	9.67	0.30
DITMCO	4.20	5.23	0.37
INS THERM	0.99	0.99	0.18
INS TORQ MTR	2.98	2.98	0.01
INS CABLE PLUG	10.64	10.64	0.30
INS GYRO	1.00	1.00	0.73
INS GCA	0.92	0.92	0.75
INS PIGA	0.53	0.53	1.20
REP VER	2.26	2.26	1.01
COVER HSG REP	1.02	1.02	0.02
LEAK TEST	3.40	3.40	1.19
REP LEAKS	2.70	2.70	0.18
PRE VIB	3.01	2.12	1.58
VIB	2.59	3.42	1.42
POST VIB	2.38	1.59	1.34
PERFORMANCE	25.65	17.18	1.09
WING V BIAS	8.26	5.45	0.68
CHANGE ID	0.86	0.86	0.28
STAGE OUT	2.15	2.15	1.00

Average Process Hours: 100.08

Average Manhours: 88.03

Additionally, each of the documents for both the MGS and GSP were cross-checked to remove any discrepancies which may have existed between the two. The following rules were applied to resolve any inconsistency in primary data received from AGMC. (See pages 3 and 5 for definitions of repair operation and transfer, respectively.)

a. A repair operation or transfer had to appear on both documents and be verified by AGMC floor managers as belonging to the respective repair line in the position shown before inclusion in the simulation model.

b. Any discrepancy in repair operation or transfer process times was either resolved with the AGMC staff or the documents with the latest date were used.

Resources Data

Data with respect to the actual physical utilization of men and equipment were obtained entirely by personal interview with the respective MGS and GSP repair line managers. Specifically, the line managers were able to identify which group of men, a total of four groups were identified, was responsible for each repair operation as well as the number of men it took to do each operation. The line managers provided the same information with respect to which set of test/handling equipment was used during each repair activity. In this case, the line managers identified twelve distinct sets of test/handling

equipment. The reader is referred to Table 5 for the repair resource data which were input to the model as Matrix No. 1.

Service Time Distributions

Each repair operation or transfer is subject to a service time which is a random variable. For purposes of this thesis, the service times are presumed to follow one of four different distributions. The distributions chosen as relevant to mechanical/electronic repair processes are the rectangular, exponential, normal and log-normal.[3] See Table 6 for service time data input to the model as Matrix No. 2. The reasons for selecting the assumed distributions are explained below.

The distribution assumptions were necessary because, theoretically, the choice of a service time distribution for each repair operation should be based on actual observation of the respective operations. However, the time required to conduct actual observations for some fifty-eight different operations is so immense that it precludes an attempt by a thesis team.

For the simulation model the researchers chose to use approximated distributions using only one parameter, the mean, which was based on historical records. Distribution types were assigned to each operation according to the following guidelines which are based on previous simulation

---

[3]The FORTRAN subroutine for the generation of log-normal deviates is presented in Appendix C.

TABLE 5

MODEL DATA MATRIX NO. 1
NETWORK AND RESOURCE REQUIREMENTS

Activity Number	Activity	Transfers		Group		Equipment Set		
		Destination Activity	Transfer Fraction	Number	Man/ Activity	Set 1	Set 2	Set 3
1	Preparation			1	2	1		
2	Stage In			2	1	2		
3	MALVER			3	1	4		
4	T*	35	.020					
5	Repair CD-2			2	1	2		
6	T	10	.500					
7	DITMCO			2	2	3		
8	T	10	.420					
9	Repair Shields			2	1	2		
10	T	12	.991					
11	Overstress Check			2	1	2		
12	T	14	.590					
13	Refurbish Parts			2	1	2		
14	T	16	.720					
15	R&R BWH			2	2	2		
16	T	17	.710					
17	R&R T Detector			2	2	2		
18	T	20	.680					
19	R&R P-92			2	2	2		
20	T	22	.270					
21	R&R GSP			2	2	2		
22	T	24	.470					
23	R&R D-37			2	2	2		

*T = Transfer.

TABLE 5 --Continued

Activity Number	Activity	Transfers: Destination Activity	Transfers: Transfer Fraction	Group: Number	Group: Man/ Activity	Equipment Set: Set 1	Equipment Set: Set 2	Equipment Set: Set 3
24	T	26	.590					
25	R&R MGSC			2	2	2		
26	T	37	.720					
27	Repair BWH			2	2	2		
28	Functional Test			3	1	4		
29	T	3	.012					
30	T	35	.694					
31	Performance Test			3	1	4		
32	T	3	.018					
33	T	35	.0					
34	Wing V Bias			3	1	4		
35	Stage Out			2	1	2		
36	Ship (MGS)			1	2	1		
37	T	35	.194			(End MGS)		
	Start GSP							
51	Stage In			4	1	-		
52	Data Acquisition			2	1	-		
53	T	GSP5	.900					
54	MALVER			3	1	4 & 5		
55	Remove Housing			4	1	7		
56	Remove Shrouds			4	1	8		
57	T	GSP66	.128					
58	Minor Repair			4	1	8		
59	T	GSP66	.808					
60	Mod BWH			4	1	8		
61	Open Funct Test			3	1	5 & (4 or 6)		

TABLE 5--Continued

Activity Number	Activity	Transfers: Destination Activity	Transfers: Transfer Fraction	Group: Number	Group: Man/ Activity	Equipment Set: Set 1	Equipment Set: Set 2	Equipment Set: Set 3
62	R&R Modules			4	1	8		
63	T	GSP15	.840					
64	Change ID			4	1			
65	T	GSP17	.993					
66	R&R Torque Motor			4	1	11		
67	T	GSP19	.480					
68	R&R Gyro			4	1	8		
69	T	GSP21	.295					
70	R&R PIGA							
71	T	GSP23	.468					
72	R&R GCA			4	1	8		
73	T	GSP25	.936					
74	R&R Resolver			4	1	8		
75	T	GSP27	.910					
76	R&R Thermistor			4	1	8		
77	T	GSP29	.872					
78	R&R Cable Plug			4	1	8		
79	T	GSP31	.769					
80	Screen Modules			4	1	8		
81	T	GSP37	.967					
82	Repair Housings			4	1	-		
83	T	GSP35	.538					
84	Refurbish Parts			4	1	-		
85	T	GSP37	.974					
86	Repair Axis			4	1	8 & 11		
87	T	GSP39	.987					
88	R&R Align Block			4	1	8		

TABLE 5--Continued

Activity Number	Activity	Transfers: Destination Activity	Transfers: Transfer Fraction	Group: Number	Group: Man/ Activity	Equipment Set: Set 1	Equipment Set: Set 2	Equipment Set: Set 3
89	T	GSP41	.987					
90	Relieve Cable Tens.			4	1	7 or 8		
91	T	GSP43	.763					
92	DITMCO			4	1	3		
93	T	GSP48	.455					
94	Open Function Test			3	1	5 & (4 or 6)		
95	T	GSP48	.106					
96	Fine Balance			4	1	10		
97	Install Housing			4	1	7		
98	T	GSP57	.539					
99	Fine Balance			4	1	10		
100	Install Housing			4	1	7		
101	Pre-Vib. Test			3	1	5 & (4 or 6)		
102	T	GSP5	.051					
103	Vibration Test			3	1	12		
104	T	GSP5	.120					
105	Post Vib. Test			3	1	5 & (4 or 6)		
106	T	GSP5	.186					
107	Performance Test			3	1	6		
108	T	GSP5	.05					
109	T	GSP62	.320					
110	Wing V Bias			3	1	6		
111	T	GSP5	.050					
112	Purge Fill			4	1	9		
113	T	GSP65	.820					
114	Repair Leaks			4	1	7		
115	Stage Out			4	1	-		
116	T	GSP62	.400					

TABLE 6

MODEL DATA MATRIX NO. 2

SERVICE TIMES AND MISCELLANEOUS

Activity Number	Service Time Distrubitons: Dist.* Type #	PARAM A	PARAM B	PARAM C	Sim. Table #	Sub-Model Activity Type**
1	3	126	12			1
2	3	951	95			1
3	1	1296	253			1
5	4	164	144	131		1
7	1	322	64			1
9	2	102				1
11	2	468				1
13	4	100	88	80		1
15	4	1125	990	900	71	1
17	4	40	35	32	72	1
19	4	88	77	70	73	1
21	4 }+	162	142	129	74	5
	4	100	88	80		
23	4	106	93	84	75	1
25	4	61	53	48	76	1
27	4	635	558	508		1
28	1	935	187			1
31	1	3477	695			1

*Distribution Types	Parameters: A	B	C
1. Rectangular	Mean	1/2 Width	-
2. Exponential	Mean	-	-
3. Normal	Mean	S. Dev.	-
4 Lognormal	Mean	Mode	MIN

**Sub-Model Activity Types

1. Simple/Men/Set 1 only (iterative model)
2. Simple/Men/Set 1 and Set 2
3. Simple/Men/Set 1 or Set 2
4. Simple/Men/Set 1 and (Set 2 or Set 3)
5. R&R/Men/Set 1/Awaiting Parts Queue

+Service time split into remove, and replace.

TABLE 6 --Continued

Activity Number	Service Time Distributions: Dist.* Type #	PARAM A	PARAM B	PARAM C	Sim. Table #	Sub-Model Activity Type**
34	1	970	194			1
35	3	222	22			1
36	3	593	59			1
	MGS ENDS					
	GSP STARTS					
51	3	184	18			1++
52	3	104	10			1++
54	1	854	171			2
55	3	285	28			1
56	3	102	10			1
58	2	97				1
60	4	967	851	773		1
61	1	226	45			4
62	4	170	149	136	81	1++
64	3	25	2			1
66	4	400	352	320	82	1
68	4	140	123	112	83	1
70	4 }+	53	46	42	84	5
	4	53	46	42		
72	4	193	169	154	85	1
74	4	145	127	116	86	1
76	4	20	17	16	87	1
78	4	1199	1055	959	88	1
80	4	91	80	72		1
82	2	102				1++
84	2	100				1++
86	4	4711	4145	3768		2
88	4	145	127	116		1
90	4	609	535	487		3
92	1	523	105			1
94	1	226	45			4
96	4	513	451	410		1
97	3	532	53			1
99	4	513	451	410		1
100	3	532	53			1
101	1	301	60			4
103	1	342	68			1
105	1	238	48			4

++Activities use dummy equipment set number.

TABLE 6 --Continued

Activity Number	Service Time Distributions Dist.* Type #	PARAM A	PARAM B	PARAM C	Sim. Table #	Sub-Model Activity Type**
107	1	2565	513			1
110	1	826	165			1
112	1	340	68			1
114	2	270				1
115	3	215	21			1++

work on the Minuteman II MGS/GSP by Whitson and Carney (20), and from fifteen years of experience in gyro platform and avionics repair by one of the authors.

a. A rectangular distribution was used if:

1. The service time was machine dependent, e.g., a test at an automatic station;

2. If service times within a given range were equally likely.

b. An exponential distribution was used if the service time was unpredictable, such as a random repair operation where the required service is often brief but will occasionally be extensive.

c. A normal distribution was used if the operation was man dependent and of a routine administrative nature, such as the Stage-in and Stage-out repair operations.

d. A log-normal distribution was used if the operation was man dependent and a routine repair activity. Most repair operations came under this category.

Once an appropriate distribution had been assigned to a repair operation, estimates of its respective parameters were made by the research team. The mean (parameter A) was available in each case but other parameters were approximated as follows:

a. Rectangular Distribution Parameter B, the half-width, was set at twenty percent of the mean. This percentage was also used by Whitson and Carney (20:91-99).

b. Normal Distribution Parameter B, the standard deviation, was set at ten percent of the mean.

c. Log-normal Distribution Parameter B, the mode was set at eighty-eight percent of the mean and Parameter C, the minimum value, was set at eighty percent of the mean. The researchers derived these parameter values after inspection of known log-normal distributions including those used by Whitson and Carney (20:91-99).

In summary, the data underlying the model is combination of standard historical data used by AGMC, raw data attained by personal investigation and interviews on the MGS/GSP repair line, and approximations based on probability theory and experience. The data were not the result of record sampling or direct observation. Therefore, several assumptions concerning the validity of the simulation model's underlying data was necessary. The assumptions are as follows:

a. Standard data, in particular, for repair transfer and repair operation mean service times are representative of the actual processes in existence at AGMC.

b. The four distribution types and their method of assignment to service times are a reasonable approximation.

c. The approximation of distribution parameters as previously discussed is reasonable.

Testing the Research Hypothesis

Research Hypothesis

A simulation model of the MGS repair process can be developed that reflects the actual MGS repair process at AGMC.

Design to Determine Model Steady State Operation

One of the first steps in the model validation procedure is the determination of the simulation model's achievement of steady state operation. Steady state is essentially the point at which differences in successive observations of the model's performance are statistically indistinguishable (17:209). By reaching steady state, the model builder is assured that any output variation noted when exercising the model is the result of a change in input and is not caused by variation in the model itself.

Basically, the approach used to test for steady state operation was to track the behavior of specific variables from initialization of the simulation. Variables tracked for this purpose were the transfer fractions of Activity 6 and the input and output rates of the MGS. The repair transfer fraction was used to estimate the achievement of steady state.

Table 7 gives the progressive repair transfer fractions simulated for Activity 6. Figure 9 presents a graph of the same information for Activity 6. The graph shows that the figures stabilized after about twenty periods

TABLE 7

PROGRESSIVE TRANSFER FRACTION

ACTIVITY 6

Period	Fraction	Period	Fraction	Period	Fraction
1	.611	11	.509	21	.500
2	.573	12	.507	22	.502
3	.526	13	.512	23	.502
4	.523	14	.509	24	.489
5	.513	15	.505	25	.507
6	.485	16	.499	26	.538
7	.480	17	.493	27	.51
8	.500	18	.489	28	.508
9	.570	19	.490	29	.505
10	.505	20	.497	30	.502

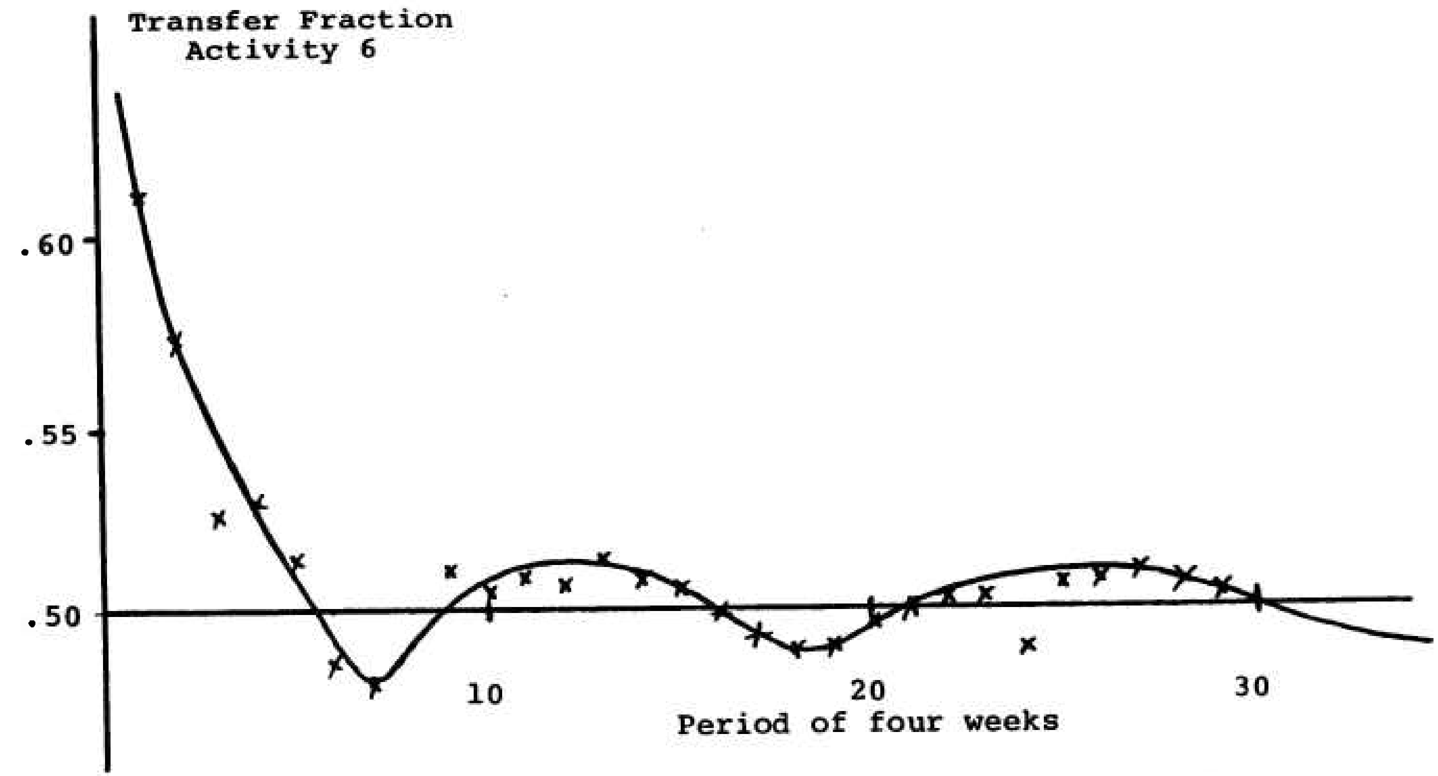

Figure 9. Progressive Value of Transfer Fraction of Activity 6

(eighty weeks of simulated operation, one period equals four weeks of simulated operation), but because the simulation had been set up to run for thirty periods, then a further twenty periods,[4] the thirtieth period was judged to be a suitable estimate of steady state occurrence.

The test for steady state operation was to take the MGS outputs from time periods twenty-one through thirty, Sample A, and to compare these with the MGS outputs from time periods forty-one through fifty, Sample B. The Mann-Whitney test of central tendency was used to test the outputs at the ninety-five percent confidence level. A nonparametric test was used because the distribution of the MGS was not known to be normal. The Mann-Whitney test was applied as follows:

a. Hypothesis to be tested

H_0 median (X_A) = median (X_B)

H_1 median $(X_A) \neq$ median (X_A)

$N_A = 10$

$N_B = 10$

$\alpha/2 = .025$

b. Sample data, sample size (N) was 10.

Sample A	39	40	40	41	42	38	41	42	38	40
Sample B	39	43	37	42	40	38	42	40	40	39

[4]After thirty periods statistics gathered during the transient phase were printed out, then reset to zero so that steady state statistics could be accrued during the next twenty periods.

c. Ranking of the data

	B	B	A	A	B	B	A	B	B	B	A
	37	38	38	38	39	39	39	40	40	40	40
Rank	1	3	3	3	6	6	6	9.17	9.17	9.17	9.17

	A	A	A	A	B	B	A	A	B
	40	40	41	41	42	42	42	42	42
Rank	9.17	9.17	14.5	14.5	17.5	17.5	17.5	17.5	20

d. Computations

$$\Sigma A = W_A = 103.51$$

$$E(W) = 1/2\ N_A\ (N_A + N_B + 1)$$

$$= 1/2\ .10\ (21)$$

$$= 105$$

$$\sigma_W^2 = 1/12\ N_A N_B\ (N_A + N_B + 1)$$

$$= 1/12 \cdot 10 \cdot 10\ (21)$$

Therefore,

$$\sigma_W = 12.228$$

$$Z = \frac{W_A - E(w)}{\sigma_w}$$

$$= \frac{103.57 - 105}{13.228}$$

$$= -.1126$$

Therefore,

$$P_r = (Z \leq -.1126) = .4559$$

$$.4559 > .025$$

Therefore,

cannot reject H_0.

The results of this test show that the MGS output per period for periods forty-one to fifty are almost identical to those from periods twenty-one to thirty; therefore, the researchers could conclude that the model was in steady state operation after the thirtieth time period.

Design to Verify the Model

Once steady state operation had been achieved, verification of the model was begun. The simulation model was initially run to permit assessment of its reliability. Data used in the model was real-world data obtained from AGMC, but could have been synthetic because validity of the model was not yet in question. Assessment of reliability is essentially the same as computer program debugging, a process which stops when the programmer believes the program is giving the results expected from known inputs.

The range of checks that were accomplished to verify the model are as follows:

a. Check for the presence of all activities in the model and correct interactions between activities.

b. Check for the correct generation of statistics, for example:

1. Correct MGS input rate.

2. Consistent output with no undue queueing within the model.

3. Correct repair transfer fractions.

4. Correct logic.

c. Check for correct generation of log-normal deviates by the FORTRAN subroutine.

d. Check that computer program tables were recording data as specified.

Most of the above checks were made by inspection and manual calculation at random points in the model. All results were satisfactory and the model was deemed to be operating as intended.

Several examples of the verification checks that were performed are as follows:

a. MGS input inter-arrival Time (IAT)

$$\text{IAT simulated} = \frac{\text{time units}}{\text{arrivals}} = \frac{1440000}{1206}$$

$$= 1194.03 \text{ units}$$

$$\text{Specified} = 1200$$

$$\text{Error} = 5\%$$

b. Repair transfer fractions

Activity	Specified Fraction	Simulated Fraction	Error
6	.5	.497	.6%
77	.872	.863	1%
98	.359	.368	2.69%

c. Activity 55 was chosen for a Logic Check because it is the model activity with the most sources. The simulation showed that Activity 55 had 1411 entries. A manual count of the expected number entries to Activity 55 from all sources totaled 1411.

d. A check of the FORTRAN subroutine for generating log-normal deviates[5] for Activity 5 showed the following data:

1. Mean = 164
2. Mode = 144
3. Minimum = 131
4. Z = -1.027655

Computationally, it was determined that the subroutine should produce a log-normal deviate of 163 which was found to be correct upon inspection.

Based on the foregoing checks, the researchers concluded that the model was reliable and was therefore verified.

Design to Test the Model's Validity

Validation, as was discussed earlier, follows verification and tests the agreement between the behavior of the model and that of the real system. Shannon has pointed out that statistical tests play a key role in establishing validity (17:227). Therefore, a comprehensive set of statistical validity tests were devised to evaluate the model. Specifically, the following areas were evaluated in comparison with the real-world situation to determine the model's validity.

---

[5]The FORTRAN subroutine is presented in Appendix C.

a. MGS input rate and arrival probability distribution.

b. MGS output rate.

c. Replacement rate of GSP (GSP input rate).

d. GSP output rate.

e. Replacement rate of PIGA (PIGA input rate).

f. Consumption of manhours for MGS and GSP processed.

g. Consumption of process hours for MGS and GSP processed.

In the following paragraphs the validation check of each of the above areas will be presented under a separate heading.

MGS input rate. AGMC historical records indicated that the mean MGS input rate was forty per month which corresponds to one per twelve hours for twenty, twenty-four-hour work days per month. Normally, the model builder would expect the MGS arrival rate distribution to follow a poisson distribution, but inspection of the actual inputs to the MGS repair line revealed that the uniform distribution more accurately represented the actual MGS arrival rate. The researchers found that simulation runs using a rectangular[6] distribution interarrival time of 12 ± 2.4 hours best reflected the real world situation at AGMC.

[6]The rectangular distribution is the continuous counterpart of the discrete uniform distribution.

<u>MGS output rate</u>. The researchers have inferred from Wagner's discussion on queueing theory, that any repair process should output, on the average, at the same rate as the input (19:453-486). From this the researcher can conclude that given an actual mean input rate of forty per month, the mean output rate should also be forty. The following hypothesis was therefore tested at the ninety-five percent confidence level using the Mann-Whitney test of Central Tendency, where simulation model output rate = X_A and actual AGMC mean input rate = X_B. Sample size (N) is 10.

a. Hypothesis to be tested

H_0 median (X_A) = median (X_B)

H_1 median $(X_A) \neq$ median (X_B)

$N_A = 10;\ N_B = 10;\ \alpha/2 = .025$

b. Sample data

X_A = 39 40 40 42 38 40 42 37 43 39

X_B = 10 values of 40

c. Computations

Ranking leads to $\Sigma A = W_A = 100$

$E(w) = 1/2\ N_A\ (N_A + N_B + 1) = 105$

$\sigma_w^2 = 1/12\ N_A N_B\ (N_A + N_B + 1) = 105$

$\sigma_w^2 = 13.228$

$$Z = \frac{W_A - E(w)}{\sigma_w}$$

$$= \frac{100 - 105}{13.228}$$

$= .3779$

$$PR\ (Z < -.3779) = .352 > \alpha/2 = .025$$

Therefore, cannot reject H_0.

Therefore, accept output rate as valid.

GSP replacement rate. Because the GSP replacement rate is a function of the number of MGS input, an appropriate test is one that checks how closely the simulated ratio of GSP replaced to MGS input matches the real-world ratio. The Student's "t" test was deemed suitable because of the assumption that the underlying distribution was normal and because the standard deviation was only known for the simulated data. Let Y be the random variable of GSP replacement to MGS input ratio. Also let $\bar{y}$ be the sample mean of the simulated ratio of GSP replaced to MGS input, and let μ be the actual AGMC mean ratio of GSP replaced to MGS input.

$$Y = \frac{\text{GSP replaced (IN)}}{\text{MGS input (IN)}}$$

a. Sample data

Sample size is 20. Simulated data from periods 31 to 50, Table 8.

$$\bar{y} = .739$$

$$SD(y) = .091 = Sy$$

b. AGMC data

$$\mu = .73$$

TABLE 8

BASIC SIMULATION RESULTS
(STEADY-STATE)

Simulated Period Number*	Transfer Fraction Activity #6	Quantities/Period					GSP (IN) / MGS (IN)	PIGA (IN) / GSP (IN)
		MGS		GSP		PIGA		
		IN**	OUT	IN	OUT	IN		
31	.421	40	42	25	33	38	.625	1.520
32	.518	40	40	24	33	20	.600	.833
33	.559	40	40	31	31	36	.775	1.161
34	.546	40	38	33	29	31	.825	.939
35	.5[illegible]	40	40	33	31	40	.825	1.212
36	.545	41	43	33	32	40	.805	1.212
37	.544	41	37	30	32	31	.730	1.033
38	.520	40	43	31	34	30	.775	.967
39	.572	40	42	27	28	29	.675	1.074
40	.576	40	38	29	28	36	.725	1.125
41	.507	40	39	25	25	28	.625	1.120
42	.497	40	40	25	26	22	.625	.880
43	.486	40	40	35	27	38	.875	1.080
44	.480	40	42	27	32	35	.675	1.296
45	.478	39	38	31	26	35	.790	1.129
46	.480	41	40	31	32	40	.756	1.290
47	.477	40	42	28	33	33	.700	1.178
48	.477	40	37	28	28	23	.700	.821
49	.479	41	43	28	29	32	.725	1.143
50	.479	40	39	38	25	27	.950	.710

*Twenty steady-state test periods of four weeks each.

**IN and OUT are with respect to respective repair lines.

c. Hypothesis to be tested

$H_0 \; \bar{y} = \mu = .73$

$H_1 \; \bar{y} \neq \mu \neq .73$

$n = 20; \quad \alpha/2 = .025$

d. Computations

$$t = \frac{\mu - \bar{y}}{Sy/\sqrt{n}}$$

$$= \frac{.73 - .739}{.091/\sqrt{20}}$$

$$= -.442$$

for $1 - \alpha/2 = .975$; degrees of freedom = 19

$t_{.975,19} = \pm 2.093$

$t = -.442 > -2.093$

Therefore, cannot reject H_0.

Therefore, accept GSP replacement rate as valid.

GSP output rate. The GSP output was tested using the Mann-Whitney Test of Central Tendency at the ninety-five percent confidence level. Sample A (X_A) is simulated data and consists of the GSP output observations for periods 41 through 50 given in Table 8 . Sample size (N_A) is 10. Sample B(X_B) data was taken from AGMC records for MM III Workload, FY-76, dated 13 January 1976 and portrays GSP outputs for the months of July through December 1975.

a. Sample data

X_A 25 26 27 32 26 32 33 28 29 25

X_B 33 27 32 26 26 33

b. Hypothesis to be tested

H_0 median (X_A) = median (X_B)

H_1 median (X_A) = median (X_B)

$N_A = 10$; $N_B = 6$; $\alpha/2 = .025$

c. Computations

The result of ranking: $\Sigma B = W_B = 56.5$

$$E(w) = 1/2\ N_B\ (N_A + N_B + 1)$$
$$= 1/2\ (6)\ (17)$$
$$= 51$$

$$\sigma_w^2 = 1/12\ N_A N_B\ (N_A + N_B + 1)$$
$$= 1/2\ (6)\ (10)\ (17)$$
$$= 85$$
$$\sigma = 9.219$$

$$z = \frac{W_A - E(w)}{\sigma_w}$$
$$= \frac{56.5 - 51}{9.219}$$
$$= .5966$$

$$Pr = (z \geq .5966) = .275 > \alpha/2 = .025$$

Therefore: cannot reject H_0.

Therefore, conclude that the simulated GSP output conforms very closely with the actual output for a six-month period.

<u>PIGA replacement rate</u>. The PIGA replacement rate is a function of the number of GSP input to the repair

process. In the same manner as the GSP, the Student's "t" test was chosen as an appropriate statistical test because of the assumption that the underlying distribution was normal and because the standard deviation was only known for the simulated data. Therefore, let P be the random variable, PIGA replacement to GSP input rate. Also let $\bar{p}$ be the sample mean of the simulated ratio of PIGA replaced to GSP input, and let μ be the actual AGMC mean ratio of PIGA replaced to GSP input.

$$P = \frac{\text{PIGA replaced (IN)}}{\text{GSP input (IN)}}$$

a. Sample data

Sample size is 20. Simulated data from Table 8 for periods 31 to 50.

$\bar{p} = 1.086$

$SD(P) = .1898 = SP$

b. AGMC data

$\mu = 1.1$

c. Hypothesis to be tested

$H_0 \; \bar{p} = \mu = 1.1$

$H_1 \; \bar{p} \neq \quad \neq 1.1$

$n = 20; \quad \alpha/2 = .025$

d. Computations

$$t = \frac{\mu - \bar{p}}{Sp/\sqrt{n}}$$

$$= \frac{1.086 - 1.1}{.1898/\sqrt{20}}$$

$$= -.329$$

for $1 - \alpha/2 = .975$ at degrees of freedom = 19.

$$t_{.975,19} = \pm 2.093$$

$$t = -.329 > -2.093$$

Therefore: cannot reject H_0.

Therefore: accept PIGA replacement rate as valid.

Consumption of manhours and process hours for MGS and GSP processed. Because of the closely interrelated nature of the manhour and process hour validity checks, both are discussed within this section. The checks were used to demonstrate the validity of the simulation model by comparing the number of manhours and process hours consumed for a given number of MGS and GSP repaired with the number of hours that AGMC historical records indicated could be expected to be consumed for the same number of MGS and GSP repaired. For these tests the consumed hours measured were combined for the MGS and GSP because the simulation model output statistics were not designed to separate consumption of resources by the MGS from consumption by the GSP. The procedures followed for both the manhour and process hour comparisons were as follows:

a. Calculate simulated consumption

$$\text{Manhours (process hours)} = \left[\sum_{i=1}^{12} \text{Average Contents of Resource } i\right] *^{7} \left[\text{Total Simulated Time of Test Period.}\right]$$

---

[7] In this case and in similar calculations throughout the thesis, the asterisk is used to denote multiplication.

b. Determine from the simulation the number of MGS and GSP output in the test period (80 weeks simulated data).

c. Calculate the expected consumption hours from the product of numbers of MGS and GSPs processed, times the expected number of resource hours taken from the MM III System and Platform Flow Diagram.

d. Compare figures from the two sources.

The first subject of comparison is that of manours. The simulated average contents of resources of men were as follows:

Group	Shift	Simulation Storage No.	Average Contents[8]
1	1	121	.81
1	2	122	.39
1	3	123	No Third Shift
2	1	124	1.11
2	2	125	1.09
2	3	126	.64
3	1	127	1.70
3	2	128	1.94
3	3	129	2.14
4	1	130	1.83
4	2	131	1.22
4	3	132	No Third Shift

Total 12.87

Simulated time = 9600 hours

Simulated manhours consumption = 9600 * 12.87

= 123,552

MGS output in period = 803

GSP output in period = 584

[8]Average contents refers to the average number in use throughout the steady state test period.

Expected consumption MGS (from AGMC flow chart)	=	74.31
Expected consumption GSP (from AGMC flow chart)	=	77.59

Therefore,

Expected consumption = (76.31(803)+(77.59)(584

= 104,983

$$\text{Error} = \frac{123{,}552 - 104{,}983}{104{,}983}$$

= .176

The simulated manhour consumption is therefore 17.6 percent high. The magnitude of this error will be discussed following the process hours comparison presentation.

For the process hours comparison the simulated average contents of the twelve test/handling equipment resources (sets) identified were as follows:

Set No.	Simulation Storage No.	Average Contents[9]
1	141	.6
2	142	1.85
3	143	.24
4	144	3.45
5	145	.68
6	146	2.03
7	147	.88
8	148	.97

[9]Average contents refers to the average number in use throughout the steady state test period.

Set No.	Simulation Storage No.	Average Contents
9	149	.21
10	150	.58
11	151	.11
12	152	.31
Total		11.91

Simulated Process Hours = 11.91 * 9600

= 114,336

Expected Process Hours (from AGMC flow chart) = 74.16

Expected Process hours GSP (from AGMC flow chart) = 87.97

MGS output in period = 803

GSP output in period = 584

Expected Process Hours Total = (74.16)(803)+(87.97)(584)

= 110,924

Error $= \frac{114,336 - 110,924}{110,924}$

= .03

The simulated process hours consumption is therefore three percent high. Whereas the three percent error in the consumption of process hours is close and acceptable, the 17.6 percent error in manhours consumption is not acceptable. This was especially true in view of the fact that process hours were simulated correctly. Consequently, an error was presumed to exist in the manhours simulation. Investigation revealed that several repair operations occupied less than one man on the average whereas the simulation rounded to

one in such cases. These discrepancies due to integer values of men actually accounted for 15,688 extra manhours over the eighty-week period. See Table 9. The corrected simulated manhours then became 107,796 (123,484 - 15,688) manhours for the period. Using this corrected figure the error then became:

$$\text{Error} = \frac{107{,}796 - 104{,}983}{104{,}983}$$

$$= .027$$

Therefore, the corrected simulated manhours consumption was 2.7 percent high which agreed very closely with the error found in process hours comparison. Table 9 shows the detail of the correction on manhours consumption.

The main conclusions from the preceding discussion are twofold: first, the corrected simulation results appear valid; and second, if future work is done using this model, either the model should be modified or the correction factor determined at Table 9 applied.

Restatement of the Research Hypothesis

A simulation model of the MGS repair process can be developed that reflects the actual repair process at AGMC.

Conclusion

The researchers conclude that for thesis purposes the model can be considered valid. This conclusion of validity is based on the high number of validity tests

TABLE 9

SIMULATED MANHOURS CORRECTION

Repair Operation Number	Error in Number of Men Assigned to Operation, (Simulation)	Times Operation Simulated in Period*	Process Hours for Operation	Error in Simulated Manhours
2	+.6	804	9.51	+4587.6
3	-.29	817	12.69	-2006.6
28	-.26	699	9.35	-1699.3
31	-.31	219	34.77	-2360.5
34	-.27	217	9.7	- 568.3
35	-.14	803	2.22	- 249.5
36	-1.0	803	5.93	-4761.8
92	+.24	205	5.23	+ 257.3
101	-.3	907	3.01	- 819
103	+.32	865	3.42	+ 946.6
105	-.34	750	2.38	- 606.9
107	-.33	628	25.65	-5315.7
110	-.34	408	8.26	-1145.8

*Period = 80 weeks

Total = -15,688

Corrected Total = 123,484 - 15680

= 107,796

$$\text{Error} = \frac{107{,}796 - 104{,}983}{104{,}983}$$

= 2.7 percent high

$$\text{Manhours Correction Factor} = \frac{-15{,}688}{123{,}484} = \underline{\underline{-.127}}$$

that were successfully passed and the confidence in the underlying data base that has been expressed by AGMC management (11). The researchers therefore conclude that the research hypothesis has been supported.

CHAPTER V

DESIGN TO ANSWER THE RESEARCH QUESTIONS

The purpose of this chapter is to describe the methods used by the researchers to answer the research questions. The chapter begins with definitions of terms and concepts, establishes a basis for answering the research questions, and ends with a description of the approach to be used for answering each of the research questions.

Definition of Terms and Concepts

The following definitions from Chapter I are repeated to aid the reader. In addition, several new terms and concepts necessary for discussing the approach to answering the research questions are defined.

Repair Line. The repair line is the sequence of events undergone by the MGS, or one of its subassemblies or components as it flows through its repair process.

Activity. For purposes of the simulation model, an activity consists of either a repair operation or a transfer.

Repair Operation. Repair operation refers to the technical operation that takes place at the repair station on the repair line.

Transfer. Transfer refers to the movement of the item of interest between repair operations.

Transfer Fraction. Transfer fraction refers to the fraction of time that items subject to the transfer are to randomly move to a specified repair operation. For example, Activity 6 which is a transfer occurs with a mean rate of .5, therefore fifty percent of all output from Activity 5 will on the average be transferred by Activity 6 to Activity 8. The remaining output of Activity 5 "falls through" Activity 6 to Activity 7.

Repair Station. The repair station is the point on the repair line where the repair resources of MGS test/ handling equipment and repair technicians come together to perform a repair operation.

Repair Resources. Repair resources are the test/ handling equipment and repair technicians that perform the MGS repair operation. For purposes of the simulation model, repair technicians and other men directly involved with the progress of the MGS from receipt, through repair, to dispatch, were assigned to one of four groups. The significant test/handling equipments were assigned to one of twelve sets.

Repair Capacity. Repair capacity is the maximum work load that a repair resource can process.

Repair Resource Utility. For purposes of this research effort, utility refers to the utilization of the repair resource as a percentage of its repair capacity. For example, a utility of fifty percent would indicate a

repair resource was operating at one-half capacity, whereas a utility of 100 percent would indicate the repair resource was working at full capacity.

Repair Resource Contents. Repair resource contents is a technical term taken from the computer program output. Repair resource contents refers to the amount of a resource that is required on the average to support a particular repair operation after the model has achieved steady-state operation. For example, a number of 2.3 in the repair resource contents column for Activity 146 would indicate that on the average 2.3 GSP Test Stations are required to support the work load.

Queue. Queue refers to a waiting line that develops when the work load at a repair station exceeds the repair station's repair capacity.

Server. The concept of a server is one of the more difficult concepts in simulation. Schriber and Shannon implicitly define server as a common simulation term used to represent a combination of equipment, people and processes which perform some service for a "customer" (16; 17). A customer can be a person or an inanimate object such as a MGS. A common example of a server is the combination of counter, cash register and cashier in a supermarket. Another server example is the specific combination of repair resources such as groups of repair technicians and/or sets of test/handling equipment located at a repair station in the MGS repair line.

Establishment of a Basis for Answering the Research Questions

Prior to the actual design of an approach for answering the research questions, the researchers found it necessary to establish a relationship between MGS input rate and repair resource contents, and to establish a method for setting repair resource capacities during later simulation runs. The establishment of a linear relationship between the MGS input rate and the average contents of each resource type was important to the research effort because it permitted the use of interpolation; thereby, negating the requirement for a simulation run at every MGS input rate the researchers chose to investigate. Repair resource capacities were set by selecting utilization factors for later simulation runs. Each of the foregoing subjects is discussed in more depth in the ensuing sections.

MGS Input Rate and Repair Resource Contents Relationship. A first step in establishing the relationship was to find the unconstrained repair resource contents. The approach used was to make the initial simulation runs with all repair resource capacity constraints removed by setting all repair resource capacities at 100. Six unconstrained simulation runs were made at the following MGS input rates.[10]

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[10]A summary of all simulation runs and their purpose is presented in Appendix D.

a. 100 percent level, 15 shifts/week[11]

b. 133 percent level, 15 shifts/week

c. 200 percent level, 15 shifts/week

d. 200 percent level, 18 shifts/week

e. 200 percent level, 21 shifts/week

f. 250 percent level, 15 shifts/week

Outputs of the unconstrained simulation runs were used to develop the relationship between MGS input rate and average contents of each repair resource type. Details of the different resource types are presented in Table 10. The relationship that was developed is expressed in terms of two ratios, with Ratio 1 being a function of Ratio 2. Ratio 1 is the ratio of the higher level MGS input rate to the normal average MGS input rate. The development of Ratio 1 for each of the six unconstrained simulation runs is presented in Table 11. Ratio 2 is the Expected Value of the ratio of the average repair resource contents at the increased average MGS input rate (load) to the average repair resource contents at the normal average MGS input rate (load). The development of Ratio 2 across each of the resource types for the normal average work load and increased work loads is presented in Table 12.

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[11]Simulation runs were made at 18 and 21 shifts per week to account for the addition repair resource capacity that would be available to AGMC if they were to go to week-end work; i.e., six or seven days a week at three shifts per day.

TABLE 10

REPAIR RESOURCES CROSS REFERENCE

Simulation Storage No.	Group No.	Shift No.	Equip. Set No.	Normal Availability 15 s/w	Description
121	1	1		2	Preparation Area
122	1	2		2	Preparation Area
123	1	3		-	Preparation Area
124	2	1		8	MGS Stage-in and Repair
125	2	2		7	MGS Stage-in and Repair
126	2	3		2	MGS Stage-in and Repair
127	3	1		15	Test Area
128	3	2		14	Test Area
129	3	3		13	Test Area
130	4	1		3	GSP Repair
131	4	2		3	GSP Repair
132	4	3		-	GSP Repair
141			1	1	Preparation Equipment
142			2	3	Tilt Fixture
143			3	1	DITMCO Equipment
144			4	8	System Test Station
145			5	8	GSP Carts
146			6	3	GSP Test Stations
147			7	8	Inverting Fixtures
148			8	10	Transport Fixture
149			9	2	Leak Tester
150			10	2	Fine Balancers
151			11	1	Major Axis Tear Down Fixture
152			12	2	Vibrators

TABLE 11

RATIO #1

HIGHER LEVEL INPUT RATE/NORMAL INPUT RATE

Load i	% Level	Shifts Per Week	Input Rate MGS/ Month	MGS Inter-Arrival Time (IAT)	Ratio #1 $\frac{\text{IAT 1}}{\text{IAT i}}$
1*	100	15	40	12.0	1
2	133	15	53.3	9.0	1.333
3	200	21	80	8.4	1.428
4	200	18	80	7.2	1.666
5	200	15	80	6.0	2.000
6	250	15	100	4.8	2.500

*Normal operating level.

TABLE 12

RATIO #2*

Simulation Storage	Average Contents Load i/Average Contents Load 1					
	i=1**	i=2	i=3	i=4	i=5	i=6
121	.397	1.267	1.43	1.637	1.989	2.54
122	.397	1.267	1.46	1.687	2.065	2.51
123	.397	1.267	1.36	1.687	1.989	2.44
124	1.36	1.330	1.02	1.176	1.44	1.7
125	1.00	1.310	1.36	1.69	1.95	2.37
126	.58	1.258	2.29	1.93	3.293	4.19
127	1.62	1.234	1.64	2.00	2.400	2.89
128	2.16	1.287	1.31	1.53	1.824	2.20
129	2.03	1.340	1.33	1.61	1.832	2.39
130	1.09	1.217	1.34	1.64	1.825	2.38
131	1.09	1.217	1.3	1.64	1.88	2.41
132	1.09	1.217	1.37	1.67	1.87	2.38
141	.59	1.356	1.44	1.69	2.03	2.52
142	1.89	1.320	1.40	1.64	1.99	2.45
143	.26	1.269	1.35	1.69	2.03	2.346
144	3.42	1.304	1.4	1.69	2.02	2.46
145	.73	1.246	1.36	1.66	1.83	2.41
146	2.06	1.276	1.43	1.71	1.96	2.47

*E(Increased Load Repair Resource Contents/Normal Load Repair Resource Contents) of Simulation Storages (groups of men and sets of equipment.

**Normal.

TABLE 12--Continued

Simulation	Average Contents Load i/Average Contents Load 1					
Storage	i=1	i=2	i=3	i=4	i=5	i=6
147	.95	1.242	1.34	1.65	1.84	2.42
148	1.05	1.200	1.34	1.65	1.87	2.36
149	.21	1.285	1.43	1.71	1.95	2.48
150	.63	1.206	1.32	1.62	1.79	2.35
151	.12	1.333	1.4	1.75	2.5	2.25
152	.33	1.242	1.36	1.66	1.878	2.45
Ratio #2	1	1.276	1.4	1.667	2.001	2.47

The relationship between Ratio 1 and Ratio 2 (Ratio 1 = f(Ratio 2)) was tested using regression analysis to determine if a linear relationship existed. The relationship was further tested using the Student's "t" test and a nearly perfect linear relationship between Ratio 1 and Ratio 2 was found to exist. The linear regression computations and findings are presented for the reader in Table 13.

The establishment of a linear relationship between the MGS input rate and the average contents of each repair resource type was significant to the research effort. As was previously stated, its significance lies in the fact that a linear relationship permits the use of interpolation, a simulation run was therefore not required at every MGS input rate that the researchers chose to investigate.

Utilization Factor Selection. Once repair resource contents for varying MGS input rates and a linear relationship between Ratio 1 and Ratio 2 had been established using unconstrained simulation runs, the next step was to establish the extent to which constraints would be applied. What was needed was a method by which repair resource capacities would be set. The researchers found that a frequent objective for this type of simulation is minimization of resource consumption, or utilization for a given throughput. Mellor in his theory of job-shop scheduling implies that the achievement of equal utilization factors throughout the resource types supports the minimization of resource

TABLE 13

REGRESSION TABLE

Ratio #1 Y	Ratio #2 X	XY	Y^2	X^2	
1.000	1.000	1.000	1.000	1.000	
1.333	1.276	1.700	1.776	1.628	
1.428	1.400	1.999	2.039	1.960	
1.666	1.667	2.775	2.775	2.775	
2.000	2.001	4.000	4.000	4.000	
2.500	2.470	6.175	6.25	6.101	
9.927	9.813	17.649	17.84	17.464	N=6

$$b = \frac{N \Sigma XY - \Sigma X \Sigma Y}{N \Sigma X^2 - (\Sigma X)^2}$$

$$= \frac{6(17.649) - (9.813)(9.927)}{6(17.464) - (9.813)^2}$$

$$b = .9989$$

$$a = \frac{\Sigma Y - b\Sigma X}{N}$$

$$= \frac{9.927 - (.9989)\ 9.813}{6}$$

$$a = \underline{\underline{.02}}$$

TABLE 13--Continued

$$\Sigma Y_s^2 = \Sigma Y^2 - a\Sigma Y - b\,\Sigma\,XY$$

$$= 17.84 - (.02)(9.927) - (.9989)(17.649)$$

$$= .0118$$

$$S_{y\cdot x} = \sqrt{\frac{\Sigma Y_s^2}{N-2}}$$

$$= \sqrt{\frac{.0118}{4}}$$

$$S_{y\cdot x} = .0544$$

$$S_{y\cdot x^2} = .00296$$

$$S_b = \sqrt{\frac{S^2_{y\cdot x}}{\Sigma(x-\bar{x})^2}}$$

$$\Sigma(x-\bar{x})^2 = \Sigma X^2 - \frac{(\Sigma X)^2}{N}$$

$$= 17.464 - \frac{(9.813)^2}{6}$$

$$= 1.415$$

$$S_b = \frac{.0544}{\sqrt{1.415}}$$

$$= .04573$$

TABLE 13--Continued

a. Hypothesis to be tested

H_0: $b = E(b) = 1$ $\qquad$ $\alpha/2 = .025$

H_1: $b \neq 1$ $\qquad$ $N = 6$

b. Computations

$$t_{N-2} = \frac{b-E(b)}{S_b}$$

$$t_4 = \frac{.9989 - 1}{.04573}$$

$$= \underline{\underline{-.024}}$$

$$t_{4,.025} = -2.776 < -.024$$

Therefore: Cannot reject H_0.

Therefore: Accept hypothesis that Ratio #1 and Ratio #2 are directly proportional.

consumption objectives. Further application of the theory holds that equal utilization of each resource type will permit maximum utilization of resources as a whole (14:284). Therefore the next step was to select utilization factors at which the simulation model would be run to determine repair resource requirements. Utilization factors of .6, .7, .8 and .9 were chosen.

In summary, a basis of unconstrained repair resource contents, linear relationships and utilization factors were established before the model was ready for operation to answer the research questions.

Design to Answer Research Question Number One

Research Question Number One

For increased average MGS input rates, what additional repair resources are required? Once the basis of unconstrained repair resource contents, linear relationships and utilization factors had been established, the next step was to determine how the model would be used to answer the research question. The approach to answering the research question was to make several simulation runs at various MGS input rates with resource capacities based on differing repair resource utilization factors. From these simulation runs it was possible to determine the maximum general utilization factor (p_{max}) that could be tolerated by the repair line being simulated; i.e., the maximum general

utilization factor before at least one of the repair resources was exhausted by the given throughput rate.

Once determined, the maximum general utilization factor (p_{max}) and the previously determined unconstrained average contents for each repair resource type for each of the MGS input rates were used to determine the actual repair resource requirements for each resource for each of the increased MGS input rates. Actual computation of repair resource requirements was made using the following equation:

$$\left.\begin{array}{l}\text{Minimum Requirement}\\ \text{Resource i at}\\ \text{MGS Input Rate j}\end{array}\right\} = \frac{\left\{\begin{array}{l}\text{Average Contents}\\ \text{Resource i at MGS}\\ \text{Input Rate j}\end{array}\right.}{p_{max}}$$

The result of the above equation was rounded to the next higher integer.

The final step in answering the research question was to compare resources that are currently available at AGMC with the simulated resource requirements at each of the increased MGS input rates. This step permitted calculation of additional resource types required for each increased MGS input rate.

Design to Answer Research Question Number Two

Research Question Number Two

For increased average MGS input rates, which Depot Replacement Unit (DRU) decoupling inventories have adequate assets? The following are the specific DRU items that were investigated:

1. Transient Detector
2. P-92
3. GSP
4. D-37 (Computer)
5. MGSC
6. Gyro (G6B4)
7. PIGA
8. GCA

To answer the research question the following approach was used.

1. The model was designed to tabulate all replacements of the above listed DRU during the simulation. From these tables, it was then possible to calculate the mean number of replacements per two-week period, the respective standard deviation and cumulative probability distribution. With this statistical information the maximum likely number of replacements in a given period could be determined.

2. Data concerning the decoupling inventory stocks for each of the above-listed DRU were obtained from AGMC.

3. AGMC decoupling inventory stocks were compared with the simulated requirements to determine the number of days of supply provided by each of the inventory stocks.

Design to Answer Research Question Number Three

Research Question Number Three

For the normal average MGS input rate, what effect does a twenty-five percent reduction in the repair recycling rate have on repair resource requirements? The question was answered using the following procedure:

1. The model was adjusted to reduce all recycling percentages by twenty-five percent.

2. A simulation run was performed at the normal average MGS input rate to obtain the repair resource requirements.

3. The resource requirements at twenty-five percent recycling were then compared with normal recycling.

CHAPTER VI

ANSWERING THE RESEARCH QUESTIONS

This chapter presents the application of the design to answer as it was developed in Chapter V and the findings on an individual basis for each of the three research questions.

Research Question Number One

For Increased average MGS input rates, what additional repair resources are required?

Establishment of the Maximum General Utilization Factor

The first step in the approach to answering research question number one was the determination of the maximum general utilization factor for several differing MGS input rates. The reader is referred to page 91 for a discussion concerning utilization factor selection. Seven simulation runs with differing utilization factors (p) were made at increased MGS input rates of 133 and 200 percent.[12] The simulation runs revealed the following results.

a. At the 200 percent MGS input rate, the simulation model could not sustain a utilization factor of .8

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[12] In this case, and as is the case throughout the thesis, a MGS input rate of 100 percent is the normal average input rate of forty per month.

or above. Calculations accomplished on the basis of linear relationships showed that because of the relatively small integer values, the resource requirements were the same at p=.75 as they were at p=.8; therefore, a utilization factor of .75 was also unacceptable. A utilization factor of .7 was sustained during the simulation runs and was therefore concluded to be the maximum general utilization factor at the 200 percent MGS input rate.

b. At the 133 percent MGS input rate, the simulation model could sustain a general utilization factor of .8, however, it did so at the cost of increased average queue sizes and times in queue. Therefore a utilization factor of .7 was also the appropriate maximum general utilization factor at 133 percent MGS input rate.

As a result of utilization factor simulation runs, .7 was used as the maximum general utilization factor (p_{max}) for all subsequent simulation runs.

Calculation of Repair Resource Capacity Requirements

Application of the linear relationship of MGS input rate to average contents of each resource type and the maximum general utilization factor of .7, permitted calculation of the repair resources required for each of the following seven load situations.

MGS Input Rate	Shifts/Week	Ratio 1
100	15	1.00
150	15	1.07
150	18	1.25
150	21	1.43
200	15	1.50
200	18	1.67
200	21	2.00

Findings

The repair resource requirements for each of the increased MGS input rates is presented in detail in Table 15. For example, if the item of interest is GSP test sets and the MGS input rate of interest is 200 percent with fifteen shifts per week; the reader should refer to Table 14 to determine the Simulation Storage number of GSP test sets, locate the Simulation Storage number in the first column of Table 15, move across the row to the column headed by 200 percent, 15 s/w, to find that six GSP test sets are required. Additionally, Table 15 is used to identify those repair resources that are not adequate at the increased input rates. All repair resource requirements that exceed existing AGMC repair resources are located to the right of the heavy line drawn through the table. Determination of additional repair resource requirements is a simple manner of subtracting existing AGMC repair resources from the listed requirement.

From Table 15, it can be seen that the GSP Test Stations (Simulated Storage #146) is the most limiting repair resource and in fact could sustain an increased load

TABLE 14

REPAIR RESOURCES CROSS REFERENCE

Simulation Storage No.	Group No.	Shift No.	Equip. Set No.	Normal Availability 15 s/w	Description
121	1	1		2	Preparation Area
122	1	2		2	Preparation Area
123	1	3		-	Preparation Area
124	2	1		8	MGS Stage-in and Repair
125	2	2		7	MGS Stage-in and Repair
126	2	3		2	MGS Stage-in and Repair
127	3	1		15	Test Area
128	3	2		14	Test Area
129	3	3		13	Test Area
130	4	1		3	GSP Repair
131	4	2		3	GSP Repair
132	4	3		-	GSP Repair
141			1	1	Preparation Equipment
142			2	3	Tilt Fixture
143			3	1	DITMCO Equipment
144			4	8	System Test Station
145			5	8	GSP Carts
146			6	3	GSP Test Stations
147			7	8	Inverting Fixtures
148			8	10	Transport Fixture
149			9	2	Leak Tester
150			10	2	Fine Balancers
151			11	1	Major Axis Tear Down Fixture
152			12	2	Vibrators

TABLE 15

REPAIR RESOURCE REQUIREMENTS

Simulation Storage Number	Normal Average Contents	Existing AGMC Repair Resources	Repair Resources Required at $\rho = .7$, by Simulation						
			100% 15 S/W Ratio #1=1	150% 21 S/W 1.07	200% 18 S/W 1.25	200% 21 S/W 1.428	150% 15 S/W 1.5	200% 18 S/W 1.666	200% 15 S/W 2.0
121	.4*	2/2*	1	1	1	1	1	1	2
122	.4*	2/1*	1	1	1	1	1	1	2
123	.4*	0/1*	1	1	1	1	1	1	2
124	1.11	8	2	2	2	3	3	3	4
125	1.09	7	2	2	2	3	3	3	4
126	.64	2	1	1	2	2	2	2	2
127	1.70	15	3	3	4	4	4	5	5
128	1.94	14	3	3	4	4	5	5	6
129	2.14	13	4	4	4	5	5	6	7
130	1.02*	3/2	2	2	2	3	3	3	3
131	1.02*	3/2	2	2	2	3	3	3	3
132	1.02*	0/2	2	2	2	3	3	3	3
141	.60	1	1	1	2	2	2	2	2
142	1.85	3	3	3	4	4	4	5	6
143	.24	1	1	1	1	1	1	1	1
144	3.45	8	5	6	7	8	8	9	10
145	3.45	8	5	6	7	8	8	9	10
146	2.03	3	3	4	4	5	5	5	6
147	.88	8	2	2	2	2	2	3	3
148	.97	10	2	2	2	2	3	3	3
149	.21	2	1	1	1	1	1	1	1
150	.58	2	1	1	2	2	2	2	2
151	.11	1	1	1	1	1	1	1	1
152	.31	2	1	1	1	1	1	1	1

*Spread over three shifts.

of seven percent (Ratio 1 = 1.07) or a maximum average of forty-three MGS per month. The next most critical repair resources appear to be the Preparation Equipment (Simulated Storage #141) and the Tilt Fixtures (Simulated Storage #142), followed by the number of men per shift in the GSP Repair Area (Simulated Storage #130-132).

One distinctive finding is the apparent, very low utilization of the men in both the MGS Stage-in and Repair Area, and in the test areas. Table 16 presents the simulated average contents and utilizations of men on the various shifts, for the current number of men employed.

Initially, these findings would tend to indicate a gross error in the model. However, it also appears that the model is not at fault because of the following facts.

a. The model consumes the correct number of manhours. The reader is referred to the manhour discussion in the simulation model validation section, page 75.

b. The model produces reasonable utilization figures for the men in the preparation area and the GSP repair area. See Table 16 for simulated utilization figures.

The question remains: How can the model consume the correct number of manhours and yet reveal such low utilizations of men in some, but not all, work areas? While it is possible that more men are employed in the MGS Stage-in and Repair Area, and the test areas than are

TABLE 16

MANPOWER UTILIZATIONS

Simulation Storage Number	Shift Number	Area	Current Number of Men	Simulated Average Contents	Simulated Utilization (per man)
121	1	Preparation Area	2	.81	.407
122	2	Preparation Area	2	.39	.19[illegible]
123	-	Preparation Area	-	-	-
124	1	MGS Stage In and Repair	8	1.11	.139
125	2	MGS Stage In and Repair	7	1.09	.155
126	3	MGS Stage In and Repair	2	.64	.318
127	1	Test Area	15	1.70	.113
128	2	Test Area	14	1.94	.139
129	3	Test Area	13	2.14	.165
130	1	GSP Repair	3	1.83	.608
131	2	GSP Repair	3	1.22	.406
132	-	GSP Repair	-	-	-

needed to do the job, the researchers suspect that some other reason would account for the low utilization figures. One very possible source of the discrepancy may be the exclusion from the model of the manhours and process time consumed by Line Replaceable Units (LRU) other than the MGS and GSP; items such as the P-92, D-37 and MGSC. Unfortunately, because of time constraints the researchers were not free to investigate this apparent discrepancy.

Research Question Number Two

For increased average MGS input rates, which Depot Replacement Unit (DRU) decoupling inventories have adequate assets?[13]

Simulated DRU Requirements

DRU replacement statistics were extracted from the simulation outputs and are summarized in Table 17. The figures presented show the average simulated stock requirement for each of the eight DRU as well as standard deviations. Tabulated data for two DRUs, the GSP and the PIGA, are graphed at Figures 10 and 11 to provide a better idea of the demand distributions for the two items at average MGS input rates of 100 and 200 percent, respectively.

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[13] DRU decoupling inventory assets were considered to be adequate if there was sufficient stock on hand to support the MGS repair process for a minimum of five days.

TABLE 17

DECOUPLING INVENTORIES SIMULATION RESULTS

Simulation Table Number	Item	Simulated Stock Requirements--10 Days			
		100% Level		200% Level	
		Mean	S. Dev.	Mean	S. Dev.
72	T. Detector	5.8	2.2	11.2	3.4
73	P-92	6.0	2.0	13.4	3.5
74	GSP	14.5	2.5	28.4	3.1
75	D-37	10.0	2.2	20.3	3.7
76	MGSC	8.2	2.6	16.8	3.3
83	G6B4	11.6	3.3	23.8	3.8
84	PIGA	16.1	3.5	30.1	4.4
85	GCA	11.4	2.6	23.4	4.6

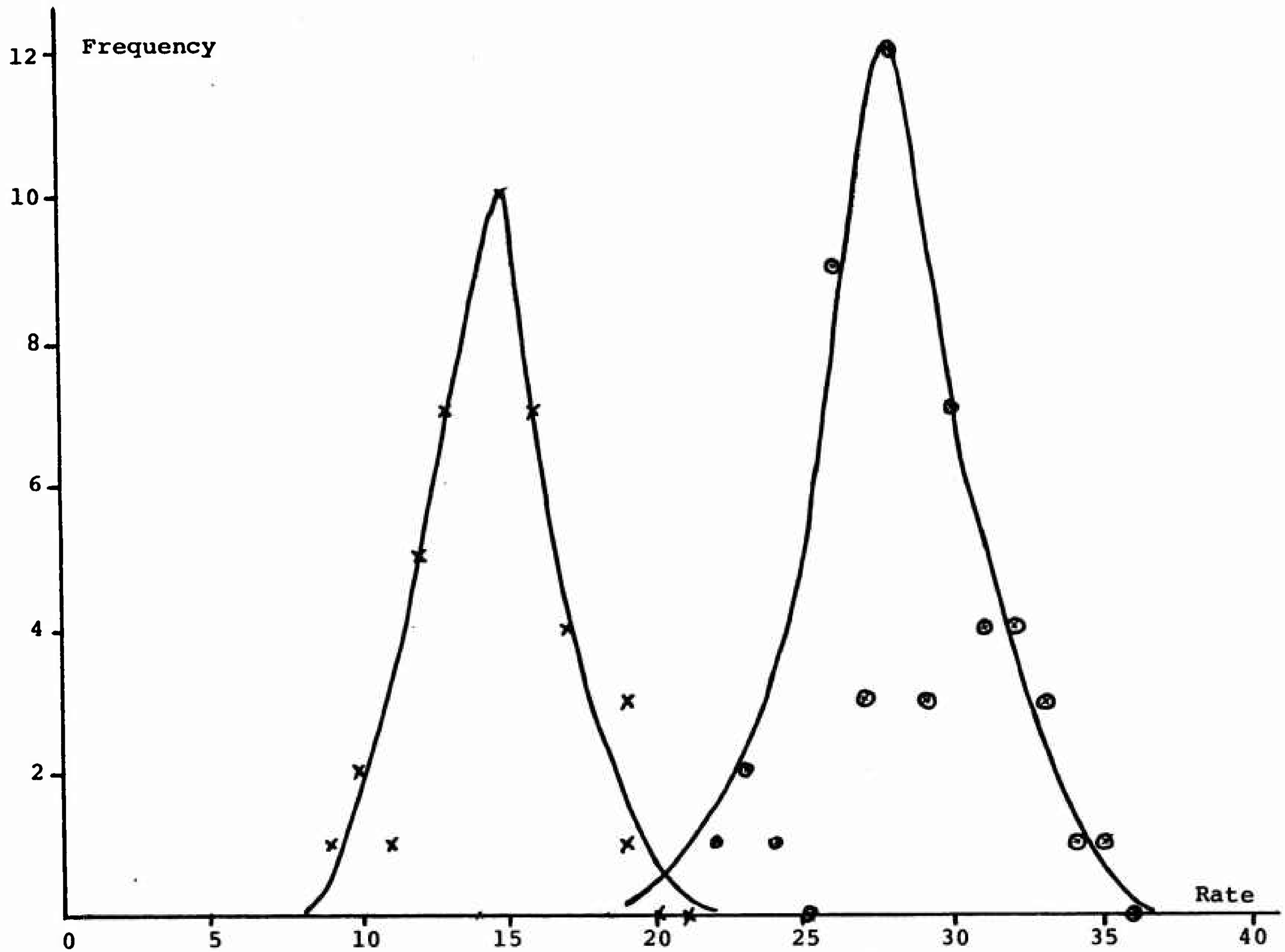

Figure 10. GSP Replacement Rate (Per Two Weeks)

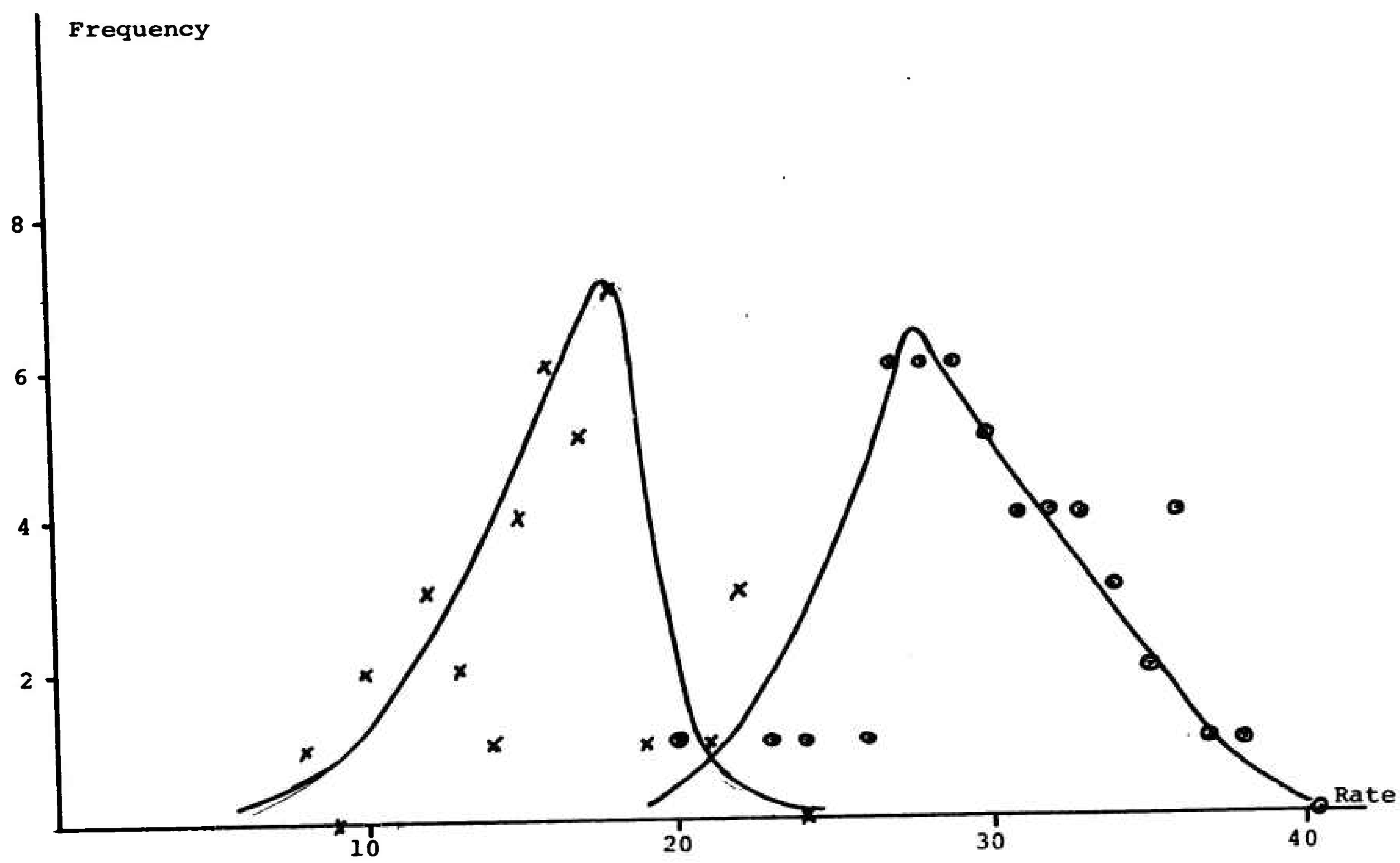

Figure 11. PIGA Replacement Rates (Per Two Weeks)

AGMC DRU Inventory Stocks

Table 18 lists details of a small sample of stock-on-hand at the end of each month for a six-month period for each of the eight DRU.

Findings

Results of the comparison between the average AGMC stock-on-hand figures for each DRU with the simulated demand for increased MGS input rates are presented in Table 19. The comparison was accomplished in terms of the average days of supply afforded by the average stock-on-hand for each DRU. Inspection of the data presented in Table 19 shows that three DRU decoupling inventory stocks (MGSC, D-37, P-92) can not adequately provide five days of supply at increased MGS input rates. It must be pointed out, however, that "days of supply" are only significant when related to the risk of resupply being delayed. If the delay exceeds the days of supply on hand then a stockout occurs and production ceases. The risk of such a delay is a matter of interpretation by the respective manager who must weigh the cost of a stockout situation versus the cost of maintaining a larger inventory.

Research Question Number Three

For the normal average MGS input rate, what effect does a twenty-five percent reduction in the repair recycling rate have on repair resource requirements?

TABLE 18

SAMPLE DATA
DECOUPLING INVENTORIES
END OF MONTH STOCK ON HAND

Item	'75 Nov	'75 Dec	'76 Jan	'76 Feb	'76 Mar	'76 Apr	Mean	Mean (Round)	Std. Dev.
T. Detector	10	9	9	5	2	4	6.5	6	3.3
P-92	2	5	10	9	3	0	4.8	5	3.9
GSP	45	44	32	33	24	18	32.7	33	10.7
D-37	9	7	6	6	7	7	7	7	1.1
MGSC	5	7	9	2	4	4	5.2	5	2.5
G6B4	17	19	20	18	20	25	19.8	20	2.8
PIGA	99	102	97	87	82	69	89.3	89	12.5
GCA	17	25	25	28	30	36	26.8	27	6.3

TABLE 19

DECOUPLING INVENTORIES SIMULATED REQUIREMENTS COMPARISON

Simulation Table Number	Item	Mean Stock on Hand*	Simulated Stock Requirements					
			10 Day Requirement**			Average Days of Supply***		
			100%	150%	200%	100%	150%	200%
72	T. Detector	6	6	9	11	10	7	5
73	P-92	5	6	10	14	8	6	4
74	GSP	33	15	21	28	22	17	12
75	D-37	7	10	15	20	7	5	4
76	MGSC	5	8	12	17	6	4	3
83	G6B4	20	12	18	24	17	11	8
84	PIGA	89	16	24	31	56	37	16
85	GCA	27	12	18	23	23	15	12

*From Table 18.

**Taken from Simulation Statistics.

***$\frac{\text{Mean Stock on Hand}}{1} * \frac{10}{\text{10-Day Requirement}}$

Reduction of Recycling

Seven transfer activities were identified in the MGS repair process to be recycling transfers. The transfer fractions for the identified activities were then reduced by twenty-five percent as presented in Table 20. A simulation run at the normal MGS input rate was then made with the reduced transfer fractions.

Findings

The researchers had expected any differences due to the reduced recycling percentages to be manifested by significant changes to the average contents of the repair resources. However, inspection of the simulation run output indicated that the twenty-five percent recycling reduction did not cause a significant reduction in the use of repair resources. A representative sampling of repair resource contents before and after the reduction is presented in Table 21. The effects of the reduced recycle percentage were so small as to be virtually undetectable in the model.

To test the above observation of no significant change, it was hypothesized that there was no significant difference at the .05 level in the average contents of resource types before, and after the recycling percentages were lowered.

TABLE 20

REDUCED RECYCLE TRANSFER FRACTIONS

Activity	Simulation Symbolic Name	Normal Transfer Fraction	Reduced* Transfer Fraction
29	ACT 29	.012	.009
32	ACT 32	.018	.013
102	GSP 52	.051	.038
104	GSP 54	.120	.090
106	GSP 56	.186	.139
108	GSP 58	.05	.037
111	GSP 61	.05	.037

*Reduced by twenty-five percent.

TABLE 21

SAMPLE AVERAGE CONTENTS BEFORE AND AFTER REDUCTION OF RECYCLING PERCENTAGES

Simulation Storage Number	Average Contents Before Change	Average Contents After Change	DIFF =D
121	.81	.8	.01
122	.39	.4	-.01
124	1.11	1.12	-.01
125	1.09	1.12	-.03
126	.64	.64	0
127	1.70	1.75	-.05
128	1.94	1.88	.06
129	2.14	2.18	-.04
130	1.83	1.66	.17
131	1.22	1.20	.02
141	.60	.60	0
142	1.85	1.88	-.03
143	.24	.24	-.01
144	3.45	3.46	-.01
145	.68	.64	.04
146	2.03	2.06	-.03
147	.88	.82	.06
148	.97	.89	.08
149	.21	.21	0
150	.58	.53	.05
151	.11	.10	-.01
152	.31	.29	.02

Mean = .0127 = $\bar{D}$.

Standard Deviation = .04939 = S_D.

a. Hypothesis to be tested

H_0: $D = 0$

H_1: $D \neq 0$

Where D = difference between corresponding samples, before and after; N = 22, and $\alpha/2 = .025$.

b. Sample data taken from Table

c. Computations

$$S_{\bar{D}} = \frac{S_D}{\sqrt{n}}$$

$$= \frac{.24939}{\sqrt{22}}$$

$$= .01053$$

$$t = \frac{\bar{D}}{S_{\bar{D}}}$$

$$= \frac{.0127}{.01053}$$

$$= 1.206$$

Therefore: $t_{.975,21} = 2.08 > t = 1.206$.

Therefore: cannot reject H_0 and conclude there is no significant difference between the before and after recycling percentages.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions and recommendations derived from the research. It is formatted to discuss the research hypothesis and each of the research questions individually, followed by general conclusions. The chapter ends with recommendations for further research and use of the simulation model.

Restatement of the Research Hypothesis

A simulation model of the MGS repair process can be developed that reflects the actual MGS repair process at AGMC.

The researchers found during verification and validation of the simulation model that the model:

a. operated as intended; and

b. passed all validity tests.

As a result, the researchers concluded that a credible simulation model had been developed that reflects the actual MGS repair process.

Restatement of Research Question Number One

For increased average MGS input rates, what additional repair resources are required?

A maximum general utilization factor of .7 for all resource types was found to be sustainable by the model and served as a basis for further simulation runs. This utilization factor seems reasonable considering that the repair process simulated resembles a job-shop repair line rather than a manufacturing assembly line. However, the utilization factor finding does rest on the assumption that equal utilization of each resource type will permit maximum utilization of resources as a whole and will support a scheduling objective of maximum throughput. Mellor, an author in the job-shop scheduling field, gives implicit support for the validity of the equal utilization assumption (14:284).

The repair resource requirements at increased MGS input rates are summarized in Table 15, page 103 of Chapter VI. The following conclusions were made from the results.

a. Existing AGMC test/handling equipment quantities are adequate in most cases of increased MGS input rate, but in several instances more equipment would be needed to support an increased work load. Details of test/handling equipment requirements are presented in Table 15, page 103.

b. Existing AGMC numbers of men employed on each shift in each of the respective work areas were found to be generally more than adequate at the normal MGS input rate. Details of manpower requirements are presented in Table 15, page 103.

The researchers conclude that the determination of addition test/handling equipment requirements, preparation area manpower requirements and GSP repair area manpower requirements for increased MGS input rates can be done with accuracy, while similar determinations for manpower in the MGS repair area and the test stations are suspect. The reasons for suspecting a discrepancy in the MGS repair area and test station manpower requirements along with speculations as to the possible cause are fully discussed in Chapter VI, pages 104 through 106.

Restatement of Research Question Number Two

For increased average MGS input rates, which Depot Replacement Unit (DRU) decoupling inventories have adequate assets?

Comparison of DRU simulated requirements at the MGS input rates of 100, 150 and 200 percent with existing DRU decoupling inventory stocks revealed that insufficient numbers of MGSC, D-37 and P-92 were available to support a five-day stock-on-hand requirement. Details of the simulated stock requirements as compared with the average stock-on-hand is presented in Table 19, page 112.

The researchers therefore conclude that the determination of decoupling inventory adequacy can be done with accuracy using the managerially supported criteria of "days of supply."

Restatement of Research Question Number Three

For the normal average MGS input rate, what effect does a twenty-five percent reduction in the repair recycling rate have on repair resource requirements?

The researchers found no significant change in the consumption of resources before and after the reduction of the recycling percentages. The reader is referred to Table 21, page 115, for a representative sampling of repair resource contents before and after the recycling percentage reduction. While it is possible to conclude that the effect of reduced recycling percentages is very small, the authors do not intend to imply that the recycle rate should not be an item of management concern.

General Conclusions

The researchers conclude that the simulation model with its known deficiencies provides a valid representation of the actual MGS repair process and can be used with confidence to predict repair resource requirements at increased MGS input rates.

Recommendations for Further Research and Use of the Model

Further Research

The following areas are recommended as subjects for further research:

a. The apparent discrepancy in manpower utilizations for the MGS repair area and the test stations should be investigated to identify its cause.

b. AGMC decoupling inventory resupply distribution data should be collected to permit a more thorough investigation of the adequacy of present stocks at increased MGS input rates.

With respect to the assumptions underlying the model the following areas are recommended for further research:

a. Even though the model gave good results, an investigation of the approximations made for service time distributions and their respective parameters may be worthwhile.

b. Even though a general maximum utilization factor of .7 seems reasonable for the type of repair process simulated, an investigation of the underlying assumption that the researchers' objective should be to equalize the utilization of all resource types may prove valuable.

Use of the Model

The model could be used with modification for repair processes other than the Minuteman III MGS for the determination of repair resource requirements at times of increased work load.

The model should also be used by AFIT/SLG as a training aid in simulation and the GPSS V simulation

language. The simulation program with its extensive use of standardization and modularization, Macro statements that simplify coding and input of data, and indirect referencing, is a simplified approach to computer simulation.

APPENDICES

APPENDIX A

DESCRIPTION OF SIMULATION MODEL

APPENDIX A

DESCRIPTION OF SIMULATION MODEL

Introduction

What follows is a description of the GPSS V simulation model used as the experimental tool of Thesis SLSR 4-76A, to investigate overload conditions on the Minuteman III Missile Guidance Set repair line. The description starts with a specification to which the model was built, explains how the model was constructed to meet the specification, and discusses use of the model.

Specification

The prime objective of the model was to represent the Minuteman III Missile Guidance Set (MGS) repair line in those areas pertinent to the study of the effects of increased input of MGS to the repair line. Because of limited time and limited potential effort that could be afforded the task, the scope of the model was restricted to simulation of only the MGS and Gyro Stabilized Platform (GSP) repair lines. Repair lines of other Depot Replaceable Units (DRU) at the same level as the GSP, and of Shop Replaceable Units (SRU) at the next lower build level, were presumed to pose no problem; i.e., it was assumed that serviceable DRUs and SRUs were always available when

a replacement item was needed. In other words, these repair lines were buffered from the principal MGS repair line by decoupling inventories that never run out of stocks. However, the same approach could not be taken with the GSP. Both the MGS and GSP repair lines had to be simulated together because of the integral use of test and repair facilities and resources.

Statistics

To answer the research questions of the thesis the model had to be capable of generating the following data for the simulation test period.

1. Queueing statistics, numbers and times in queue, for:

   (a) each repair operation,

   (b) each resource identified as a "facility" or "storage" (GPSS terms), and

   (c) awaiting parts queue, when specified.

2. The number of times each repair operation was performed.

3. Details on utilization of resources.

4. Tabulations of specified random variables.

5. "Snapshot" statistics at specified intervals (four weeks) to aid determination of steady state and troubleshooting.

6. Values of specified variables and transaction parameters (a parameter in this context is a value

peculiar to a transaction; i.e., the entity identified as the thing flowing through the model.

Model Design

Overall Structure of GPSS Model

One feature of the model is the modular construction that pervades all areas of the model, in the definition part as well as in the main program. Organization of the GPSS program (synonymous with model) was as follows:

1. Reallocate Cards. These are defining statements used to reallocate otherwise reserved core storage among GPSS entities as required.

2. Macros. These are sets of GPSS statements (not subroutines) that can be inserted into the program indirectly.

3. Functions. GPSS has the ability to accept user defined functions. The first type of function used was to generate exponential and normal deviates (now an automatic feature of GPSS V but not in earlier versions). A second type (very important to this model) was the routing function, which permits indirect routing of transfers within the model.

4. Tables. All statistical tables of interest were listed, especially those required to record the replacement rate of DRUs and SRUs.

5. <u>Storages</u>. This section specified the capacity of identified resources, being men or test/handling equipment.

6. <u>Matrices</u>. Three data matrices were specified:

(a) one to store resource requirements data for each repair operation;

(b) one to store service time data for each repair question; and

(c) one to store table numbers for operations of interest.

7. <u>Variables</u>. In GPSS, variables perform the same function as arithmetic or logical statements in other computer languages, but have to be indirectly referenced. Variables identified for this model were:

(a) <u>Variables 1-4</u>. These calculate storage numbers for groups of men as a function of the shift number.

(b) <u>Variables 11 and 12</u>. These calculate storage numbers as a function of the Equipment Set number given in the input data.

(c) One floating point variable to calculate a normal deviate.

8. <u>Initials</u>. GPSS permits the input of data via initial statements. These may be made directly with an "initial" card, or indirectly via a macro-statement.

9. Main Program--Segment 2.

(a) Generate Card. This is normally the first card in the simulation deck and is used to generate input to the model according to any process, deterministic or stochastic, within the envelope of GPSS.

(b) Activity Type 1. A distinct segment of the program has been dedicated to the simulation of one standard activity type, namely, the most common activity type, of which there are forty-eight in a total of fifty-seven repair operations. All forty-eight are simulated by the one set of GPSS statements by means of indirect addressing.

(c) Segment 2. Simulation of MGS activities; i.e., repair operations and transfers.

(d) Segment 3. Simulation of GSP activities.

(e) Segment 4--Generators. The following generator subsegments are in Segment 4:

(1) One to generate serviceable PIGA flowing back into the GSP repair line.

(2) One to generate shift data and to lock "gates" when specific resources are not used on some shifts.

(3) One to generate "snapshot" statistics throughout the simulation.

(4) One to time duration of the simulation, both to steady state and for a period thereafter.

Types of Activity

All repair operations in the model have been classified or are of the five following standard types:

1. Activity Type 1. This is the principal type of activity in the model and is used to simulate forty-eight of the fifty-seven repair operations. However, by means of indirect addressing, only one set of GPSS statements (lines 3535-3880, Appendix B) have been used to simulate all fort. ight operations. A Type 1 Activity simulates the consumption of manhours, and process hours on one set of test/handling equipment.

2. Activity Types 2-5. All five types of activity are simulated in a similar fashion but differ according to some peculiarity. All simulate the consumption of manhours, but differ in the combination of test/handling equipment sets used and whether an awaiting-parts queue is involved. Differences between Types 2-5, along with the respective program listing line numbers (Figure 1), are as follows:

(a) Type 2. Uses Equipment Sets 1 and 2, (lines 5560-5620).

(b) Type 3. Uses Equipment Sets 1 or 2, (lines 6410-6650).

(c) Type 4. Uses Equipment Set 1 and, 2 or 3 (lines 6700-6790).

(d) Type 5. Uses Equipment Set 1, and simulates an awaiting-parts queue. This type used only for the GSP and PIGA remove and replace questions (lines 4720-4990).

Model Logic

As a network, the model is simply an interconnection of repair operations and transfers between operations (together comprising activities). Within each of the standard activity types previously described, logical features are as follows:

1. A gate to open and close Shift Number 3, because in some areas the men work only two shifts.

2. Test of the gate to see if Shift Number 3 is in progress.

3. A gate to prevent progress of a job if insufficient resources remain to perform the operation at hand.

4. Tests to see if replacement data needs to be tabulated.

5. Transfers to applicable service times and next activities according to data input to the model initially.

6. For Activity Type 5 only, tests on stocks of spare GSPs (or PIGAs) to permit replacement, otherwise the respective higher level assembly is removed from its repair line and put into an awaiting-parts queue.

Model Performance

The model performs very well and as intended. Refer to Chapter IV on verification and validation of the model for a full discussion.

Use of the Model

As the model now stands (see Appendix B for listing) the model simulates the MGS/GSP repair process for 200 weeks at an MGS input rate of forty per calendar month, based on a five-day week. The following changes may be made to parameters or configuration without affecting the model logic or exceeding GPSS limitations specified in the model.

1. The MGS input rate--by altering the Generate statement at line 3530, however, the parameter specifications at the end of the statement must be retained.

2. The simulation times can be altered to suit a planned run (lines 9030-9070).

3. Requirements for snapshot statistics may be inserted as lines 8740-8840 starting with a Generate statement and ending with a Terminate statement.

4. Capacities of resources, men and test/handling equipment may be changed by changing the Storage statements between lines 1730-1790.

5. Resources data may be altered via the Macro statements at lines 2090-2240 and 2500-2780, however, the first entry (next activity number) must not be changed.

6. Service times data may be altered via the Macro statements at lines 2280-2460, and 2820-3100.

Modification

Any change other than those just described would require a modification to the model. The most probable type of change would be to the network, to insert or remove activities, or to change the transfer fractions. The latter may be changed directly by changing the respective statement, however, the insertion or deletion of repair operations will particularly effect the routing information input to the model as Function "ROUT2".

Known Deficiencies

The only significant, known deficiencies of the model are as follows: Activities 3, 28, 31 and 34 should have been simulated as Type 2 activities rather than Type 1. As simulated, the activities consume process hours on Equipment Set No. 4 only, whereas both Sets 4 and 5 should have been used together. The only effect of this deficiency is to indicate that fewer Sets #5 are required than is really the case. The difficulty is easily overcome by equating the need for Sets #5 to the need simulated for Sets #4 since they are both used together.

General Comments

To conclude, the most distinctive features of the model as a GPSS simulation are as follows:

1. the modularization and standardization within the model;

2. the extensive use of Macro statements to simplify coding; and

3. the use of indirect referencing to reduce coding to a minimum, and core required to house the program.

A significant error exists due to the method used to simulate integer quantities of men, especially where quantities were rounded up to one. This error was discussed at length in Chapter IV, in which it was stated that the error could be overcome by either modifying the model, or using the correction factor determined in Chapter IV. Satisfactory results for most, if not all, simulation objectives for which the model might be used could be obtained by using the correction factor.

APPENDIX B

COMPUTER SIMULATION PROGRAM

COMPUTER SIMULATION PROGRAM

```
5##S,R(SL) :,8,16::,8,19,31
10$:IDENT:WP1190, AFITSL FLINT 76A
12$:LIMITS:,,,10K
15$:SELECT:AF.LIB/GPSS6A
20$:FORTY:NFORM,NLNO
25 SUBROUTINE HELP1 (IX1,IX2,IX3,Z,IT)
30 AX1=IX1
35 AX2=IX2
40 AX3=IX3
45 VAR=0.75*ALOG((AX1-AX3)/(AX2-AX3))
50 AMU=ALOG(AX2-AX3)+VAR
55 T=EXP(Z*SQRT(VAR)+AMU)+AX3
60 IT=T
65 RETURN
70 END
75$:SELECT:AF.LIB/GPSS6B
80$:SELECT:AF.LIB/GPSS6C
85$:LIMITS:80,45K,-1K,8K
90:SIMULATE
0100*
110:REALLOCATE:BLO,650,FAC,0,STO,160,QUE,181,LOG,10,TAB,99,FUN,5
120:REALLOCATE:VAR,12,BVR,0,FSV,30,HSV,0,LSV,5,FMS,0,HMS,3
0130*
0140*:MACROS
0150*
160 ONE:STARTMACRO
170:QUEUE:#A
180:QUEUE:#B
190:QUEUE:#C
0200:ENDMACRO
```

```
0210*
0220 TWO;STARTMACRO
0230;TEST NE;#A,0,#B
0240;TRANSFER;,#C
0250 #B;GATE LR;LOCK2
0260 #C;ASSIGN;6,#D
0270;TEST GE;R*6,#E
0280;ENDMACRO
0290*
0300 THREE;STARTMACRO
0310;GATE SNF;#A
0320;QUEUE;#B
0330;GATE SNF;#C,#D
0340;TRANSFER;,#E
0350 #D;QUEUE;#F
0360;GATE SNF;#G
0370;ENDMACRO
0380*
0390 FOUR;STARTMACRO
0400;ENTER;#A
0410;ENTER;#B
415;ENTER;#C,#D
0420;DEPART;#E
0430;DEPART;#F
0440;DEPART;#G
0450;DEPART;#H
0460;ENDMACRO
0470*
0480 FIVE;STARTMACRO
0490;ADVANCE;#A,#B
0500;LEAVE;#C,#D
0510;LEAVE;#E
0520;LEAVE;#F
0530;TRANSFER;,#G
```

```
Ø54Ø;ENDMACRO
Ø55Ø*
Ø6ØØ*
Ø61Ø SEVEN;STARTMACRO
62Ø;TRANSFER;#A,,#B
63Ø;ASSIGN;7,#C
64Ø;TRANSFER;,#D
65Ø;ENDMACRO
Ø86Ø*
Ø87Ø ATE;STARTMACRO
Ø88Ø;INITIAL;MH1(#A,1),#B/MH1(#A,2),#C/MH1(#A,3),#D/MH1(#A,4),#E
Ø89Ø;ENDMACRO
Ø9ØØ*
Ø91Ø NINE;STARTMACRO
Ø92Ø;INITIAL;MH2(#A,1),#B/MH2(#A,2),#C/MH2(#A,3),#D/MH2(#A,4),#E
Ø93Ø;ENDMACRO
Ø94Ø*
Ø95Ø TEN;STARTMACRO
Ø96Ø;INITIAL;MH3(#A,1),#B/MH3(#C,1),#D/MH3(#E,1),#F/MH3(#G,1),#H
Ø97Ø;ENDMACRO
98Ø SIX;STARTMACRO
982;SAVEVALUE;1,FN2,XL
Ø984;SAVEVALUE;7,#A
Ø986;SAVEVALUE;8,#B
Ø988;SAVEVALUE;9,#C
99Ø;HELPB;1,X7,X8,X9,XL1,P1Ø
Ø992;ADVANCE;P1Ø
Ø994;ENDMACRO
1ØØØ*
1Ø1Ø*;FUNCTIONS
1Ø2Ø*
1Ø3Ø XPDIS;FUNCTION;RN2,C24
1Ø4Ø#Ø,Ø/.1,.1Ø4/.2,.222/.3,.355/.4,.5Ø9/.5,.69/.6,.915
1Ø5Ø#.7,1.2/.75,1.38/.8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52
```

```
1060#.94,2.81/.95,2.99/.96,3.2/.97,3.5/.98,3.9/.99,4.6
1070#.995,5.3/.998,6.2/.999,7/.9998,8
1080 SNORM;FUNCTION;RN3,C25
1090#0,-5/.00003,-4/.00135,-3/.00621,-2.5/.02275,-2
1100#.06681,-1.5/.11507,-1.2/.15866,-1/.21186,-.8/.27425,-.6
1110#.34458,-.4/.42074,-.2/.5,0/.57926,.2/.65542,.4
1120#.72575,.6/.78814,.8/.84134,1/.88493,1.2/.93319,1.5
1130#.97725,2/.99379,2.5/.99865,3/.99997,4/1,5
1140*
1150 ROUT1;FUNCTION;MH2(P1,1),D4
1160#1,ADV1/2,ADV2/3,ADV3/4,ADV4
1170*
1180 ROUT2;FUNCTION;P7,D48
1190#2,NEXT/3,NEXT/4,ACT4/6,ACT6/8,ACT8/10,ACT10/12,ACT12/14,ACT14
1200#16,ACT16/18,ACT18/20,ACT20/24,ACT24/26,ACT26/28,NEXT/29,ACT29
1210#32,ACT32/35,NEXT/36,NEXT/38,ACT38/52,NEXT/53,GSP3/56,NEXT
1220#57,GSP7/59,GSP9/61,GSP11/63,GSP13/65,GSP15/67,GSP17/69,GSP19
1230#73,GSP23/75,GSP25/77,GSP27/79,GSP29/81,GSP31/83,GSP33
1240#85,GSP35/89,GSP39/93,GSP43/97,NEXT/98,GSP48/100,NEXT
1250#101,GSP51/104,GSP54/108,GSP58/111,GSP61/113,GSP63/115,NEXT
1260#999,GSP67
1270*
1280*;TABLES
1290*
1300 1;QTABLE;121,50,50,20
1310 2;QTABLE;122,50,50,20
1320 51;QTABLE;161,50,50,20
1330 52;QTABLE;162,50,50,20
0001340 71;TABLE;RT,1,1,80,24000
0001350 72;TABLE;RT,1,1,80,24000
0001360 73;TABLE;RT,1,1,80,24000
0001370 74;TABLE;RT,1,1,80,24000
0001380 75;TABLE;RT,1,1,80,24000
0001390 76;TABLE;RT,1,1,80,24000
```

```
0001400 81$TABLE$RT,1,1,80,24000
0001410 82$TABLE$RT,1,1,80,24000
0001420 83$TABLE$RT,1,1,80,24000
0001430 84$TABLE$RT,1,1,80,24000
0001440 85$TABLE$RT,1,1,80,24000
0001450 86$TABLE$RT,1,1,80,24000
0001460 87$TABLE$RT,1,1,80,24000
0001470 88$TABLE$RT,1,1,80,24000
0001480 91$TABLE$RT,1,1,80,24000
0001490 92$TABLE$RT,1,1,80,24000
0001500 93$TABLE$MP1PF,3000,500,40
0001510 94$TABLE$MP1PF,6000,1000,50
1700*
1710*$STORAGES
1720*
1800*
1810*$MATRICES
1820*
1830 1$MATRIX$H,120,4
1840 2$MATRIX$H,120,4
1850 3$MATRIX$H,120,1
1860*
1870*$VARIABLES
1880*
1890 1$VARIABLE$X5+120
1900 2$VARIABLE$X5+123
1910 3$VARIABLE$X5+126
1920 4$VARIABLE$X5+129
1930 11$VARIABLE$P2+120
1940 12$VARIABLE$MH1(P1,4)+140
1950 NORM1$FVARIABLE$MH2(P1,3)*FN$SNORM+MH2(P1,2)
2000*
2010*$INITIALS
2020*
```

```
2030:INITIAL:X2-X3,1/X5,1
2035:INITIAL:X11,100/X12,50
2040*:MGS DATA  SERVERS
2050*
2060 ATE:MACRO:1,2,1,2,1
0002070 ATE:MACRO:2,3,2,1,2
2080 ATE:MACRO:3,4,3,1,4
0002090 ATE:MACRO:5,6,2,1,2
0002100 ATE:MACRO:7,8,2,2,3
0002110 ATE:MACRO:9,10,2,1,2
0002120 ATE:MACRO:11,12,2,1,2
0002130 ATE:MACRO:13,14,2,1,2
0002140 ATE:MACRO:15,16,2,2,2
0002150 ATE:MACRO:17,18,2,2,2
0002160 ATE:MACRO:19,20,2,2,2
0002170 ATE:MACRO:23,24,2,2,2
0002180 ATE:MACRO:25,26,2,2,2
0002190 ATE:MACRO:27,28,2,2,2
0002200 ATE:MACRO:28,29,3,1,4
0002210 ATE:MACRO:31,32,3,1,4
0002220 ATE:MACRO:34,35,3,1,4
0002230 ATE:MACRO:35,36,2,1,2
0002240 ATE:MACRO:36,38,1,2,1
2250*
2260*:MGS DATA SERVICE TIMES
2270*
0002280 NINE:MACRO:1,3,126,12,0
0002290 NINE:MACRO:2,3,951,95,0
0002300 NINE:MACRO:3,1,1269,253,0
0002310 NINE:MACRO:5,4,164,144,131
0002320 NINE:MACRO:7,1,322,64,0
0002330 NINE:MACRO:9,2,102,0,0
0002340 NINE:MACRO:11,2,468,0,0
0002350 NINE:MACRO:13,4,100,88,80
```

```
0002360 NINE;MACRO;15,4,1125,990,900
0002370 NINE;MACRO;17,4,40,35,32
0002380 NINE;MACRO;19,4,88,77,70
0002390 NINE;MACRO;23,4,106,93,84
0002400 NINE;MACRO;25,4,61,53,48
0002410 NINE;MACRO;27,4,635,558,508
0002420 NINE;MACRO;28,1,935,187,0
0002430 NINE;MACRO;31,1,3477,695,0
0002440 NINE;MACRO;34,1,970,194,0
0002450 NINE;MACRO;35,3,222,22,0
0002460 NINE;MACRO;36,3,593,59,0
2470*
2480*;GSP DATA  SERVERS
2490*
0002500 ATE;MACRO;51,52,4,1,19
0002510 ATE;MACRO;52,53,2,1,19
0002520 ATE;MACRO;55,56,4,1,7
0002530 ATE;MACRO;56,57,4,1,8
0002540 ATE;MACRO;58,59,4,1,8
0002550 ATE;MACRO;60,61,4,1,8
0002560 ATE;MACRO;62,63,4,1,8
0002570 ATE;MACRO;64,65,4,1,19
0002580 ATE;MACRO;66,67,4,1,11
0002590 ATE;MACRO;68,69,4,1,8
0002600 ATE;MACRO;72,73,4,1,8
0002610 ATE;MACRO;74,75,4,1,8
0002620 ATE;MACRO;76,77,4,1,8
0002630 ATE;MACRO;78,79,4,1,8
0002640 ATE;MACRO;80,81,4,1,8
0002650 ATE;MACRO;82,83,4,1,19
0002660 ATE;MACRO;84,85,4,1,19
0002670 ATE;MACRO;88,89,4,1,8
0002680 ATE;MACRO;92,93,4,1,3
0002690 ATE;MACRO;96,97,4,1,10
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0002700 ATE;MACRO;97,98,4,1,7
0002710 ATE;MACRO;99,100,4,1,10
0002720 ATE;MACRO;100,101,4,1,7
0002730 ATE;MACRO;103,104,3,1,12
0002740 ATE;MACRO;107,108,3,1,6
0002750 ATE;MACRO;110,111,3,1,6
0002760 ATE;MACRO;112,113,4,1,9
0002770 ATE;MACRO;114,115,4,1,7
0002780 ATE;MACRO;115,999,4,1,19
2790*
2800*;GSP DATA SERVICE TIMES
2810*
0002820 NINE;MACRO;51,3,184,18,0
0002830 NINE;MACRO;52,3,104,10,0
0002840 NINE;MACRO;55,3,285,28,0
0002850 NINE;MACRO;56,3,102,10,0
0002860 NINE;MACRO;58,2,97,0,0
0002870 NINE;MACRO;60,4,967,851,773
0002880 NINE;MACRO;62,4,170,149,136
0002890 NINE;MACRO;64,3,25,2,0
0002900 NINE;MACRO;66,4,400,352,320
0002910 NINE;MACRO;68,4,140,123,112
0002920 NINE;MACRO;72,4,193,169,154
0002930 NINE;MACRO;74,4,145,127,116
0002940 NINE;MACRO;76,4,20,17,16
2950;INITIAL;MH2(78,1),4/MH2(78,2),1199
2955;INITIAL;MH2(78,3),1055/MH2(78,4),959
0002960 NINE;MACRO;80,4,91,80,72
0002970 NINE;MACRO;82,2,102,0,0
0002980 NINE;MACRO;84,2,100,0,0
0002990 NINE;MACRO;88,4,145,127,116
0003000 NINE;MACRO;92,1,523,105,0
0003010 NINE;MACRO;96,4,513,451,410
0003020 NINE;MACRO;97,3,532,53,0
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ØØØ3Ø3Ø NINE;MACRO;99,4,513,451,41Ø
ØØØ3Ø4Ø NINE;MACRO;1ØØ,3,532,53,Ø
ØØØ3Ø5Ø NINE;MACRO;1Ø3,1,342,68,Ø
3Ø6Ø;INITIAL;MH2(1Ø7,1),1/MH2(1Ø7,2),2565
3Ø65;INITIAL;MH2(1Ø7,3),513/MH2(1Ø7,4),Ø
3Ø7Ø;INITIAL;MH2(11Ø,1),1/MH2(11Ø,2),826
3Ø75;INITIAL;MH2(11Ø,3),165/MH2(11Ø,4),Ø
ØØØ3Ø8Ø NINE;MACRO;112,1,34Ø,68,Ø
ØØØ3Ø9Ø NINE;MACRO;114,2,27Ø,Ø,Ø
ØØØ31ØØ NINE;MACRO;115,3,215,21,Ø
311Ø*
312Ø*;TABLE CROSS REFERENCE
313Ø*
ØØØ314Ø TEN;MACRO;15,71,17,72,19,73,23,75
ØØØ315Ø TEN;MACRO;25,76,62,81,66,82,68,83
ØØØ316Ø TEN;MACRO;72,85,74,86,76,87,78,88
35ØØ*
351Ø*;SEGMENT 1;ACTIVITY TYPE 1
352Ø*
353Ø;GENERATE;12ØØ,24Ø,...,12PH,5PF
3535;MARK;1PF
354Ø;ASSIGN;7,1
355Ø NEXT;ASSIGN;1,P7
356Ø;QUEUE;P1
357Ø;ASSIGN;2,MH1(P1,2)
358Ø;QUEUE;V11
359Ø;ASSIGN;3,V12
36ØØ;QUEUE;P3
361Ø;GATE SNF;P3
362Ø;TEST NE;X*2,Ø,LOK1
363Ø;TRANSFER;,LOK2
364Ø LOK1;GATE LR;LOCK2
365Ø LOK2;ASSIGN;6,V*2
366Ø;TEST GE;R*6,MH1(P1,3)
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3670;ENTER;P3
3680;ENTER;P6,MH1(P1,3)
3690;DEPART;P1
3700;DEPART;V11
3710;DEPART;P3
3720;TEST NE;MH3(P1,1),Ø,TrER1
3730;TABULATE;MH3(P1,1)
3740 TFER1;TRANSFER;,FN$ROUT1
3750*
3760 ADV1;ADVANCE;MH2(P1,2),MH2(P1,3)
3770;TRANSFER;,LEEV
3780*
3790 ADV2;ADVANCE;MH2(P1,2),FN$XPDIS
3800;TRANSFER;,LEEV
3810*
3820 ADV3;ADVANCE;V$NORM1
3830;TRANSFER;,LEEV
3840 ADV4;ADVANCE
3845 SIX;MACRO;MH2(P1,2),MH2(P1,3),MH2(P1,4)
3850 LEEV;LEAVE;P6,MH1(P1,3)
3860;LEAVE;P3
3870;ASSIGN;7,MH1(P1,1)
3880;TRANSFER;,FN$ROUT2
3890*
4500*
4510*;SEGMENT 2   MGS ACTIVITIES
4520*
4530 ACT3;ASSIGN;7,3
4540;TRANSFER;,NEXT
4550 ACT4;ADVANCE
0004560 SEVEN;MACRO;.020,ACT35,5,NEXT
4570 ACT6;ADVANCE
0004580 SEVEN;MACRO;.500,ACT10,7,NEXT
4590 ACT8;ADVANCE
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0004600 SEVEN;MACRO;.420,ACT10,9,NEXT
4610 ACT10;ADVANCE
0004620 SEVEN;MACRO;.991,ACT12,11,NEXT
4630 ACT12;ADVANCE
0004640 SEVEN;MACRO;.590,ACT14,13,NEXT
4650 ACT14;ADVANCE
0004660 SEVEN;MACRO;.720,ACT16,15,NEXT
4670 ACT16;ADVANCE
0004680 SEVEN;MACRO;.710,ACT18,17,NEXT
4690 ACT18;ADVANCE
0004700 SEVEN;MACRO;.680,ACT20,19,NEXT
4710 ACT20;TRANSFER;.270,,ACT22
4720 ACT21;ADVANCE
4730 ONE;MACRO;21,122,142
4740 TWO;MACRO;X2,LOK3,LOK4,V2,2
4750;ENTER;142
4760;ENTER;P6,2
4770;DEPART;142
4780;DEPART;122
4790;DEPART;21
4800;TEST E;P8,0,REP1
4810;TABULATE;74
4820 SIX;MACRO;162,142,129
4830;SPLIT;1,GSP1
4840 REP1;TEST GE;X11,1,AWP1
4850;SAVEVALUE;11-,1
4860 SIX;MACRO;100,88,80
4870;LEAVE;P6,2
4880;LEAVE;142
4890;TRANSFER;,ACT22
4900 AWP1;LEAVE;P6,2
4910;LEAVE;142
4920;QUEUE;161
4930;ASSIGN;8,1
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4940 LAG1;ADVANCE;2400
4950;TEST LE;X11,0,DEP61
4960;TRANSFER;,LAG1
4970 DEP61;DEPART;161
4980;PRIORITY;2,BUFFER
4990;TRANSFER;,ACT21
5000 ACT22;ADVANCE
0005010 SEVEN;MACRO;.470,ACT24,23,NEXT
5020 ACT24;ADVANCE
0005030 SEVEN;MACRO;.590,ACT26,25,NEXT
5040 ACT26;ADVANCE
0005050 SEVEN;MACRO;.720,ACT37,27,NEXT
0005060 ACT29;TRANSFER;.012,,ACT3
0005070 SEVEN;MACRO;.694,ACT35,31,NEXT
0005080 ACT32;TRANSFER;.018,,ACT3
0005090 SEVEN;MACRO;.000,ACT35,34,NEXT
5100 ACT35;ASSIGN;7,35
5110;TRANSFER;,NEXT
0005120 ACT37;ADVANCE
0005130 SEVEN;MACRO;.194,ACT35,28,NEXT
0005140 ACT38;TABULATE;91
5145;TABULATE;93
5150;TRANSFER;,FIN
5500*
5510*;SEGMENT 3   GSP ACTIVITIES
5520*
5530 GSP1;ASSIGN;7,51
5535;MARK;1PF
5540;TRANSFER;,NEXT
0005550 GSP3;TRANSFER;.900,,GSP5
0005560 ONE;MACRO;54,123,144
0005570 ;QUEUE;145
0005580 ;GATE SNF;144
0005590 ;GATE SNF;145
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0005600 TWO;MACRO;X3,LOK5,LOK6,V3,1
5610 FOUR;MACRO;144,145,P6,1,54,123,144,145
0005620 FIVE;MACRO;854,171,P6,1,145,144,GSP5
5630 GSP5;ASSIGN;7,55
5640;TRANSFER;,NEXT
0005650 GSP7;ADVANCE
5660 SEVEN;MACRO;.128,GSP66,58,NEXT
0005670 GSP9;ADVANCE
5680 SEVEN;MACRO;.808,GSP66,60,NEXT
0005690 GSP11;ADVANCE
0005700 ONE;MACRO;61,123,145
0005710 TWO;MACRO;X3,LOK7,LOK8,V3,1
0005720 THREE;MACRO;145,144,144,TRY1,ENT1,146,146
0005730 FOUR;MACRO;146,145,P6,1,146,144,145,123
0005740 ;DEPART;61
0005750 FIVE;MACRO;226,45,P6,1,145,146,GSP12
0005760 ENT1;ADVANCE
0005770 FOUR;MACRO;144,145,P6,1,144,145,123,61
0005780 FIVE;MACRO;226,45,P6,1,145,144,GSP12
5790 GSP12;ASSIGN;7,62
5800;TRANSFER;,NEXT
0005810 GSP13;ADVANCE
5820 SEVEN;MACRO;.840,GSP15,64,NEXT
0005830 GSP15;ADVANCE
5840 SEVEN;MACRO;.993,GSP17,66,NEXT
0005850 GSP17;ADVANCE
5860 SEVEN;MACRO;.480,GSP19,68,NEXT
0005870 GSP19;TRANSFER;.295,,GSP21
0005880 GSP20;ADVANCE
0005890 ONE;MACRO;70,124,148
0005900 TWO;MACRO;X4,LOK9,LOK10,V4,1
0005910 ;ENTER;148
0005920 ;ENTER;P6,1
0005930 ;DEPART;148
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$DEPART$124
$DEPART$70
$TEST E$P8,0,REP2
$TABULATE$84
SIX$MACRO$53,46,42
$SPLIT$1,FIN
REP2$TEST GE$X12,1,AWP2
$SAVEVALUE$12-,1
SIX$MACRO$53,46,42
$LEAVE$P6,1
$LEAVE$148
$TRANSFER$,GSP21
AWP2$LEAVE$P6,1
$LEAVE$148
$QUEUE$162
$ASSIGN$8,1
LAG2$ADVANCE$400
$TEST LE$X12,0,DEP62
$TRANSFER$,LAG2
DEP62$DEPART$162
$PRIORITY$2,BUFFER
$TRANSFER$,GSP20
GSP21$ADVANCE
SEVEN$MACRO$.468,GSP23,72,NEXT
GSP23$ADVANCE
SEVEN$MACRO$.936,GSP25,74,NEXT
GSP25$ADVANCE
SEVEN$MACRO$.910,GSP27,76,NEXT
GSP27$ADVANCE
SEVEN$MACRO$.872,GSP29,78,NEXT
GSP29$ADVANCE
SEVEN$MACRO$.769,GSP31,80,NEXT
GSP31$ADVANCE
SEVEN$MACRO$.967,GSP33,82,NEXT
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0006280 GSP33;ADVANCE
0006290 SEVEN;MACRO;.538,GSP35,84,NEXT
0006300 GSP35;TRANSFER;.974,,GSP37
0006310 ONE;MACRO;86,124,148
0006320 ;QUEUE;151
0006330 ;GATE SNF;148
0006340 ;GATE SNF;151
0006350 TWO;MACRO;X4,LOK11,LOK12,V4,1
0006360 FOUR;MACRO;148,151,P6,1,86,124,148,151
6365 SIX;MACRO;4711,4145,3768
6370 FIVE;MACRO;0,0,P6,1,151,148,GSP37
0006380 GSP37;ADVANCE
6390 SEVEN;MACRO;.987,GSP39,88,NEXT
0006400 GSP39;TRANSFER;.987,,GSP41
0006410 GSP40;QUEUE;90
0006420 ;QUEUE;124
0006430 TWO;MACRO;X4,LOK13,LOK14,V4,1
0006440 ;QUEUE;147
0006450 ;GATE SNF;147,TRY11
0006460 ;ENTER;147
0006470 ;ENTER;P6,1
0006480 ;DEPART;147
0006490 ;DEPART;124
0006500 ;DEPART;90
6510 SIX;MACRO;609,535,487
0006520 ;LEAVE;P6,1
0006530 ;LEAVE;147
0006540 ;TRANSFER;,GSP41
0006550 TRY11;QUEUE;148
0006560 ;GATE SNF;148
0006570 ;ENTER;148
0006580 ;ENTER;P6,1
0006590 ;DEPART;148
0006600 ;DEPART;147
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0006610 ;DEPART;124
0006620 ;DEPART;90
6630 SIX;MACRO;609,535,487
0006640 ;LEAVE;P6,1
0006650 ;LEAVE;148
6660*
0006670 GSP41;ADVANCE
6680 SEVEN;MACRO;.763,GSP43,92,NEXT
0006690 GSP43;TRANSFER;.455,,GSP48
6700 GSP44;ADVANCE
0006710 ONE;MACRO;94,123,145
0006720 TWO;MACRO;X3,LOK15,LOK16,V3,1
0006730 THREE;MACRO;145,144,144,TRY2,ENT2,146,146
0006740 FOUR;MACRO;146,145,P6,1,146,144,145,123
0006750 ;DEPART;94
0006760 FIVE;MACRO;226,45,P6,1,145,146,GSP45
0006770 ENT2;ADVANCE
0006780 FOUR;MACRO;144,145,P6,1,144,145,123,94
0006790 FIVE;MACRO;226,45,P6,1,145,144,GSP45
0006800 GSP45;ADVANCE
6810 SEVEN;MACRO;.106,GSP48,96,NEXT
0006820 GSP48;ADVANCE
6830 SEVEN;MACRO;.359,GSP51,99,NEXT
0006840 GSP51;ADVANCE
0006850 ONE;MACRO;101,123,145
0006860 TWO;MACRO;X3,LOK17,LOK18,V3,1
0006870 THREE;MACRO;145,144,144,TRY3,ENT3,146,146
0006880 FOUR;MACRO;146,145,P6,1,146,144,145,123
0006890 ;DEPART;101
0006900 FIVE;MACRO;301,60,P6,1,145,146,GSP52
0006910 ENT3;ADVANCE
0006920 FOUR;MACRO;144,145,P6,1,144,145,123,101
0006930 FIVE;MACRO;301,60,P6,1,145,144,GSP52
0006940 GSP52;ADVANCE
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6950 SEVEN;MACRO;.051,GSP5,103,NEXT
0006960 GSP54;TRANSFER;.120,,GSP5
6970 GSP55;ADVANCE
0006980 ONE;MACRO;105,123,145
0006990 TWO;MACRO;X3,LOK19,LOK20,V3,1
0007000 THREE;MACRO;145,144,144,TRY4,ENT4,146,146
0007010 FOUR;MACRO;146,145,P6,1,146,144,145,123
0007020 ;DEPART;105
0007030 FIVE;MACRO;238,48,P6,1,145,146,GSP56
0007040 ENT4;ADVANCE
0007050 FOUR;MACRO;144,145,P6,1,144,145,123,105
0007060 FIVE;MACRO;238,48,P6,1,145,144,GSP56
0007070 GSP56;ADVANCE
7080 SEVEN;MACRO;.186,GSP5,107,NEXT
7090 GSP58;TRANSFER;.050,,GSP5
7100 SEVEN;MACRO;.320,GSP62,110,NEXT
0007110 GSP61;ADVANCE
7120 SEVEN;MACRO;.050,GSP5,112,NEXT
7123 GSP62;ASSIGN;7,112
7125;TRANSFER;,NEXT
0007130 GSP63;ADVANCE
7140 SEVEN;MACRO;.820,GSP6",114,NEXT
7150 GSP65;ASSIGN;7,115
7160;TRANSFER;,NEXT
0007170 GSP66;TRANSFER;.400,GSP13,GSP12
0007180 GSP67;SAVEVALUE;11+,1
0007190 ;TABULATE;92
7195;TABULATE;94
0007200 FIN;TERMINATE
8500*
8510*;SEGMENT 4    GENERATORS
8520*
8530*;DECOUPLING INVENTORIES
8540*
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```
8550:GENERATE:500
8560:SAVEVALUE:12+,1
8570:TERMINATE
8580*
8590*:SHIFT TIMER
8600*
8610:GENERATE:800
8620:SAVEVALUE:5+,1
8630:TEST NE:X5,3,LOG2
8640 SHIF3:TEST NE:X5,4,SAV1
8650:TERMINATE
8660 LOG2:LOGIC S:LOCK2
8670:TRANSFER:,SHIF3
8680 SAV1:SAVEVALUE:5,1
8690:LOGIC R:LOCK2
8700:TERMINATE
8710*
8720*:Q STATISTICS
8730*
9000*
9010*:SIMULATION TIMER
9020*
9030:GENERATE:480000
9040:TERMINATE:1
9050:START:3
9060:RESET
9070:START:2
9080:END
10000$:ENDJOB
```

APPENDIX C

FORTRAN SUBROUTINE FOR GENERATING LOG-NORMAL DEVIATES

APPENDIX C

FORTRAN SUBROUTINE FOR GENERATING LOG-NORMAL DEVIATES

```
      SUBROUTINE HELP1 (IX1,IX2,IX3,Z,IT)
      AX1=IX1
      AX2=IX2
      AX3=IX3
      VAR=0.75*ALOG((AX1-AX3)/(AX2-AX3))
      AMU=ALOG(AX2-AX3)+VAR
      T=EXP(Z*SQRT(VAR)+AMU)+AX3
      IT=T
      RETURN
      END
```

APPENDIX D

SIMULATION RUN SUMMARY

APPENDIX D

SIMULATION RUN SUMMARY

Run #	Input Rate %	Equiv. Shifts/ Week	SIM Resource Category	Interar. Time Mean	Interar. Time Dist Type	No RN Gens. Used	Util. Factor ρ	Purpose
1	100	15	NORM	12	EXP	1	-	To test arrival distribution and random no generators
2	100	15	NORM	12	EXP	3	-	
3*	100	15	NORM	12	RECT	3	-	
4	100	15	100	12	RECT	3	-	Unconstrained runs to determine relationships for average contents of resources
5	133	15	100	9	RECT	3	-	
6	200	15	100	6	RECT	3	-	
7	200	18	100	7.2	RECT	3	-	
8	200	21	100	8.4	RECT	3	-	
9	250	15	100	4.8	RECT	3	-	
10**	133	15	Per ρ	9	RECT	3	.7	To find the maximum utilization (ρ) for the repair network
11	133	15	Per ρ	9	RECT	3	.8	
12	133	15	Per ρ	9	RECT	3	.9	
13	200	15	Per ρ	6	RECT	3	.6	
14**	200	15	Per ρ	6	RECT	3	.7	
15	200	15	Per ρ	6	RECT	3	.8	
16	200	15	Per ρ	6	RECT	3	.9	
17	100	15	NORM	12	RECT	3	-	Reduced recycling percentages

*Standard Rum 100%
**Standard Run 133%   Also used to establish decoupling inventory requirements.
***Standard Run 200%

SELECTED BIBLIOGRAPHY

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A. REFERENCES CITED

1. Blanchard, Benjamin S., Jr., and E. Edward Lowery. Maintainability Principles and Practices. New York: McGraw-Hill, Inc., 1969.

2. Boeing Aerospace Company. "Existing Computer Aids for Logistics Analysis." Code Ident. No. 81205, Number DI80-17691-2, Seattle, Washington, 1974.

3. Buffa, Elwood S., and William H. Taubert. Production-Inventory Systems: Planning and Control. Homewood, Illinois: Richard D. Irwin, Inc., 1972.

4. Burt, Lt Col John, USAF, and Lt Robert T. Benbow, USN. "G-200 Bearing: An Analysis Concerning the Reliability of an Inexpensive Part and Its Effect on Depot Level Repair Cost." Unpublished Master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 16 January 1974.

5. England, William B., and Michiel R. Leenders. Purchasing and Materiels Management. Homewood, Illinois: Richard D. Irwin, Inc., 1975.

6. Genet, Russell M. "Avionics Cost Reduction Through Improved Tests." Aerospace Guidance and Metrology Center, Newark AFS, Newark, Ohio, 1974.

7. ________. "The Application of Operations Analysis to Achieve Major Cost Savings in the Repair Process at AGMC." Aerospace Guidance and Metrology Center, Newark AFS, Newark, Ohio. 10 July 1970.

8. ________. "Results of a Logistical Analysis of the Depot Level Repair of Air Force Inertial Guidance Systems." Aerospace Guidance and Metrology Center, Newark AFS, Newark, Ohio. 10 March 1971.

9. ________, Chief, Industrial Engineering Support Division, Plans and Program Office, Aerospace Guidance and Metrology Center. Newark AFS, Newark, Ohio. Personal interview. 15 August 1975.

10. Hansen, Captain Paul G., USAF. Minuteman Systems Program Office (SPO)/MNNG, Air Force Systems Command, Norton AFB, California. Telephone interview. 25 August 1975.

11. Hurst, Robert. Minuteman II, III Program Manager, Aerospace Guidance and Metrology Center. Newark AFS, Newark, Ohio. Personal interview. 6 October 1975.

12. Iwerson, Major Alfred, Jr., USAF, Captain Richard R. Berry, USAF, and Captain James E. Brawner, Jr., USAF. "Cost Analysis of the KT-73 Inertial Measurement Unit Repair Process Using Graphical Evaluation Review Technique Simulation." Unpublished Master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, January, 1975.

13. LaFleur, Jean M., and Susano Mascarro. "A Study of Peacetime Multishift Operations Within Air Force Logistics Command." Unpublished Master's thesis, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1974.

14. Mellor, P. "A Review of Job Shop Scheduling," Operational Research Quarterly, Vol. 17, No. 2 (June, 1966), pp. 161-171, as reprinted in Gene K. Groff and John F. Muth, eds., Operations Management: Selected Readings. Homewood, Illinois: Richard D. Irwin, Inc., 1969.

15. Pieruschka, Erich. Principles of Reliability. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1963.

16. Schriber, Thomas J. Simulation Using GPSS. New York: John Wiley and Sons, 1974.

17. Shannon, Robert E. Systems Simulation: The Art and Science. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1975.

18. U.S. Department of the Air Force. Minuteman III Missile Guidance System. Technical Order 21M-LGM30G-2-12, 1 November 1974. Washington: Government Printing Office, 1974.

19. Wagner, Harvey M. Principles of Management Science. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1970.

20. Whitson, William F., and John M. Carney. "A GPSS Model of the Minuteman II Missile Guidance Set (MGS) Repair Process." Unpublished Master's thesis, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1975.

B. RELATED SOURCES

Absher, Jerry M., and Ramon R. Rachel. "Management Analysis for Bits and Pieces Affecting End Item Repair." Unpublished Master's thesis, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1967.

Bell, T. E. "Computer Analysis. Objectives and Problems in Simulating Computers." RAND Corporation Report AD-760-749. Santa Monica, California: The RAND Corporation, July, 1972.

Bock, Robert H., and William K. Holstein. Production, Planning and Control: Text and Readings. Columbus, Ohio: Charles E. Merrill Books, Inc., 1968.

Cochran, E. G. Planning Production Costs: Using the Improvement Curve. San Francisco, California: Chandler Publishing Company, 1968.

Evans, Bethel Q., and Thurston A. Thompson. "Queueing and Linear Programming Theory Applied to an Engine Repair Facility." Unpublished Master's thesis, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1968.

Meitzler, Thomas. Proceedings of the Quarterly Meeting of the Life Cycle Cost Task Group of the Joint Services Data Exchange for Inertial Systems, Anaheim, California, April 23-25, 1974. Aerospace Guidance and Metrology Center, Newark AFS, Newark, Ohio. 1974.

Minh, Doan. "An Evaluation of Heuristic Scheduling Rules by Using a Zero-One Linear Programming Approach." Unpublished Master's thesis, School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1975.

Peck, Merton J., and Frederic M. Scherer. The Weapons Acquisition Process: An Economic Analysis. Boston, Massachusetts: Harvard University, 1962.

Spencer, Glenn, Hyman Kolkowitz, and Ronald Dilks. "A Total Ship Simulation Model for the DDG-2 Class Guided Missile Destroyer--Volume 1, Discussion." Bureau of Naval Personnel, Report No. PRR-68-5, August, 1968.

Watson, Squadron Leader E. B., RAAF, and Major Charles R. Waterman, Jr., USAF. "A Cost Analysis of the KT-73 Inertial Measurement Unit Repair Process Using Absorbing Markov Chains." Unpublished Master's thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 14 August, 1974.